# G.E.C. Journal

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**THE ELECTRIFICATION OF THE MANCHESTER-ALTRINCHAM RAILWAY.**
**A six-coach train at Stretford station during trials; electrical equipment by The General Electric Co., Ltd.**

G.E.C. Journal

VOL. II. AUGUST, 1931. No. 2.

# The Electrification of the Manchester-Altrincham Railway.

By E. H. CROFT, A.M.Inst.C.E., A.M.I.E.E.

Traction Dept., Witton Engineering Works of the General Electric Co., Ltd.

THE electrification of the Manchester, South Junction and Altrincham Railway, which was officially inaugurated on the 11th of May, 1931, had been projected for some considerable time, as throughout its 80 years of steam working, this line has carried some of the heaviest suburban traffic in the provinces. Apart from its importance in this respect, however, the electrification itself is one of the most interesting of recent years, being the first in this country to operate on a 1,500 volt D.C. supply since the Ministry of Transport adopted this voltage as a standard.

The line, which is approximately nine miles in length, is jointly owned by the London, Midland and Scottish, and the London and North Eastern Railway Companies, and serves the densely populated residential area situated between Manchester and Altrincham. While with steam operation the time taken for the journey between the two termini at Manchester and Altrincham was 27 minutes with eight intermediate stops, with electric traction the total will be reduced to 24 minutes notwithstanding the proposed addition of two new stations at Navigation Road, Altrincham, and Dane Road, Sale (fig. 1). Existing stations on the line have, where necessary, been brought up-to-date, and

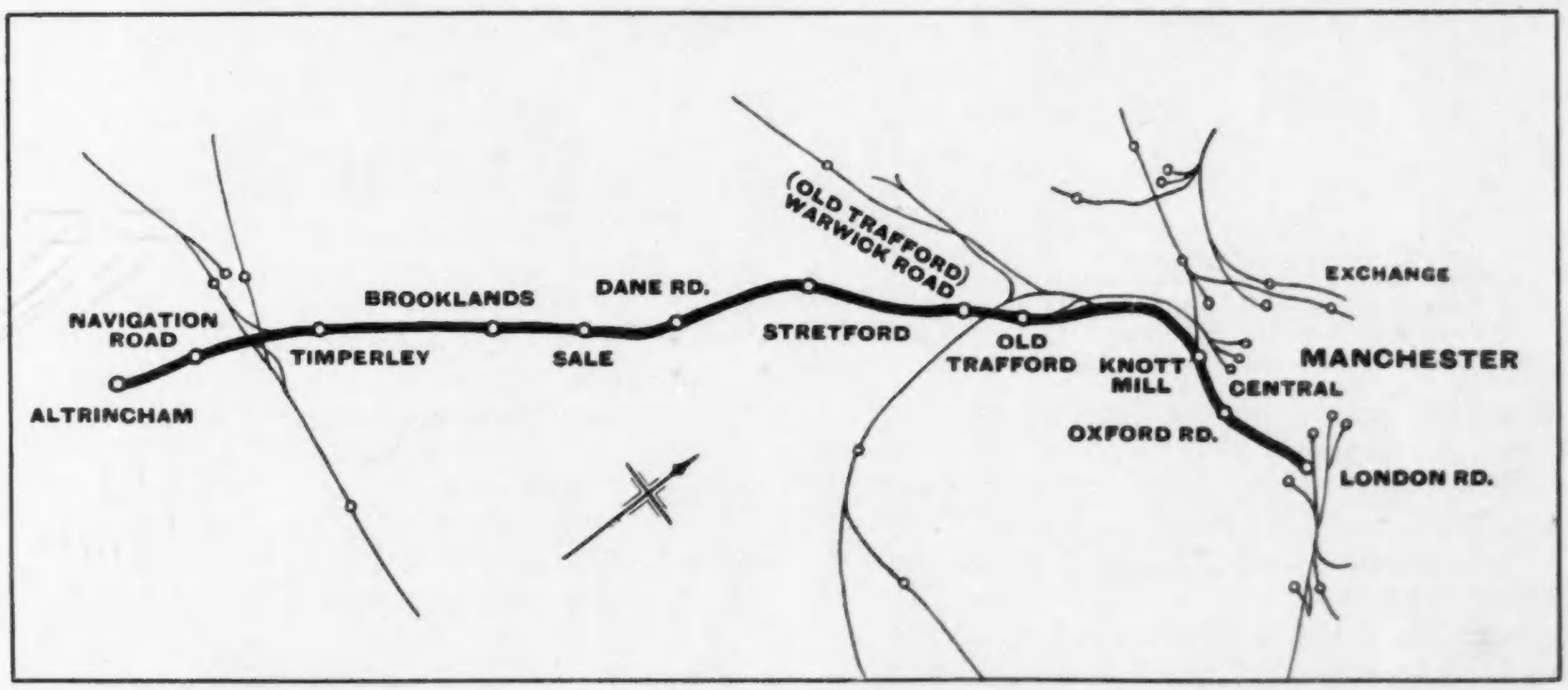


Fig. 1.—Map of the Manchester, South Junction and Altrincham Railway showing the stations served.

the provision of two additional tracks between Old Trafford and Sale will allow express trains to pass stopping trains between these points and make a non-stop journey between the two termini in 15

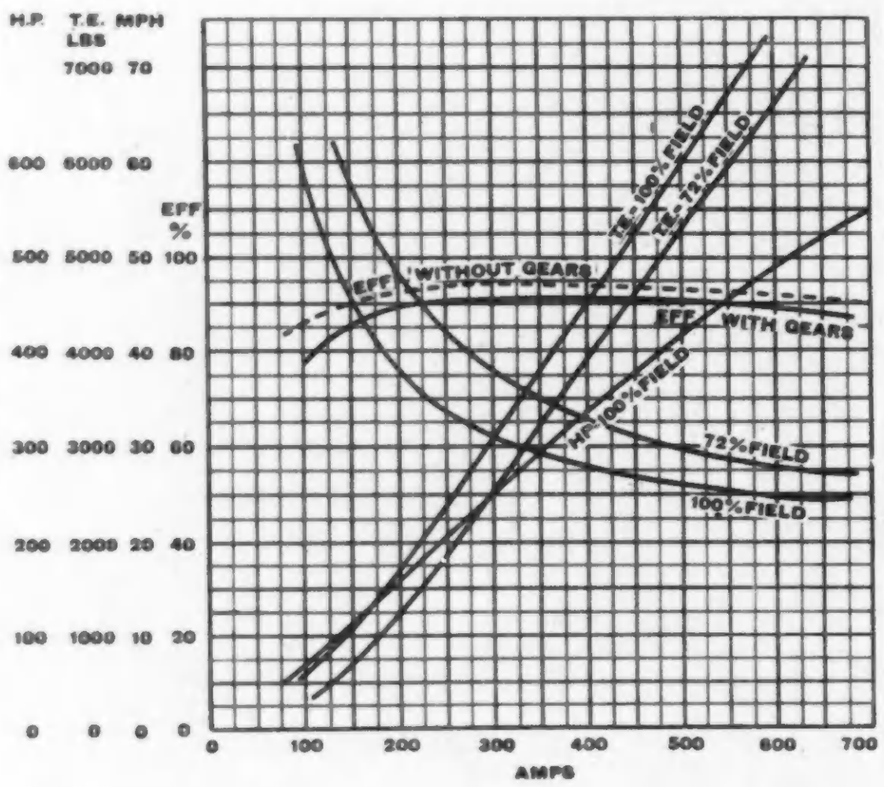


**Fig. 2.—Performance curves of the traction motors.**

minutes. Moreover, it is intended to increase the number of trains on week-days from 99 to 127, and on Sundays from 38 to 44. Thus, the line now offers suburban passengers an efficient service which can compete successfully with existing road transport systems.

Power for operating the railway is obtained from the Longford Bridge sub-station of the Stretford Urban District Council, and is transmitted at 11,000 volts, 3 phase, 50 cycles to two traction sub-stations at Old Trafford and Timperley, where the supply is rectified and fed to the overhead conductor system of the railway at 1,500 volts.

**ROLLING STOCK.**

The electrical rolling stock required for the electrification comprises 24 motor coaches, 22 driving trailer coaches and 22 non-driving trailer coaches, the whole of the electrical equipment for these coaches having been manufactured and supplied by The General Electric Co., Ltd., to the Oerlikon system. The coaches are of the ordinary

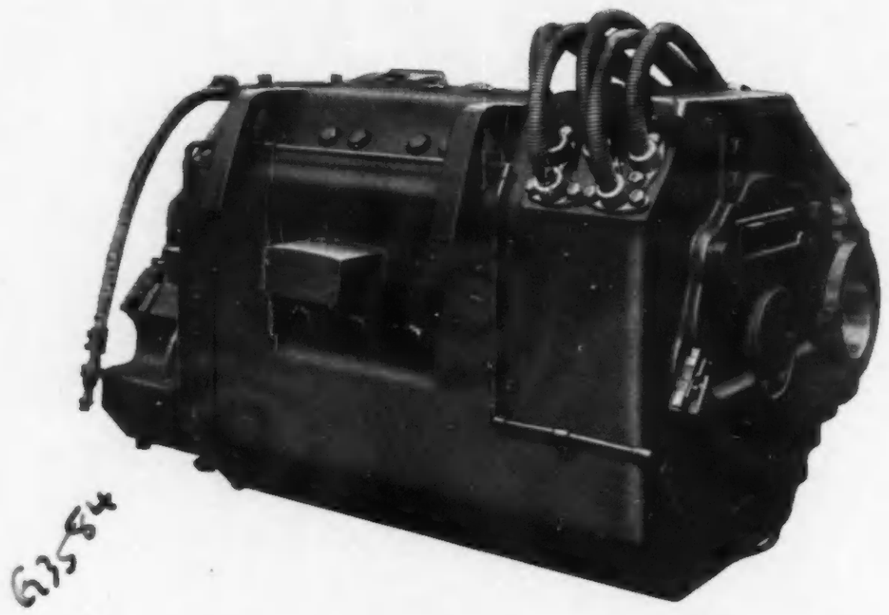

**Fig. 3.—One of the 328 h.p. 675-volt D.C. traction motors.**

type of compartment stock well known on British railways, a single driving end being provided on each motor coach and driving trailer coach. The trains are usually made up of three or six coaches for normal and rush hour duties respectively, although the electrical equipment of the coaches allows for maximum flexibility in the choice of train formation. A six-coach train at Stretford station during preliminary trials is shown on page 54.

With three-coach train units, an acceleration of 1.43 miles per hour per second is called for, the figure being slightly less for larger train units. This acceleration is well within the capacity of the motors.

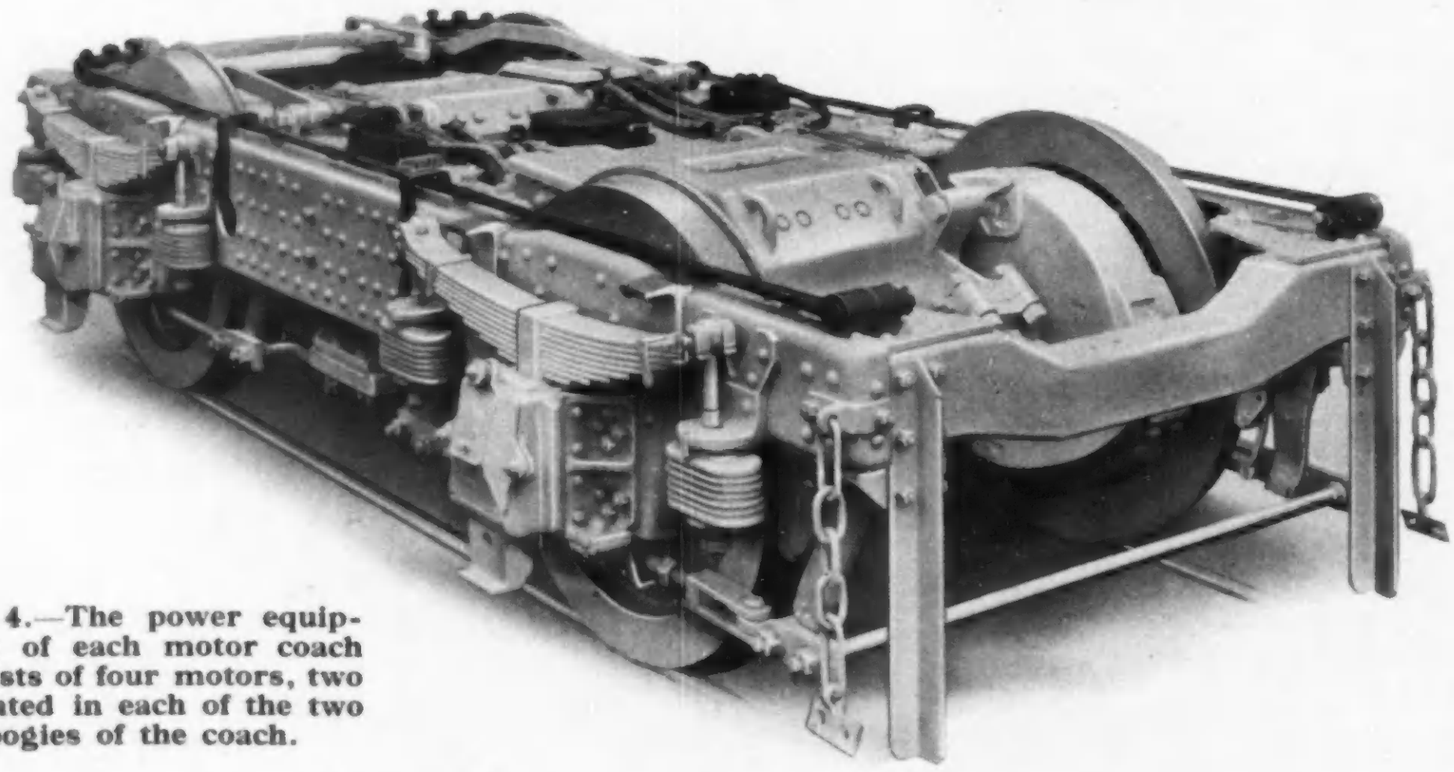

**Fig. 4.—The power equipment of each motor coach consists of four motors, two mounted in each of the two bogies of the coach.**

Each motor coach develops a tractive effort during acceleration of approximately 23,000 lbs., while the approximate tractive efforts per coach corresponding to the hourly and continuous ratings of the motor are as follows :—

| | | |
|---|---|---|
| Hourly rate, full field .. | .. | 17,600 lbs. |
| Continuous rate, full field | .. | 11,000 „ |
| Hourly rate, weak field .. | .. | 15,000 „ |
| Continuous rate, weak field | .. | 9,000 „ |

The weights of the coaches completely equipped but unloaded are as follows :—

| | |
|---|---|
| Motor coach .. .. | 57 tons approx. |
| Driving trailer and trailer coaches .. .. .. | 30 „ „ |

### MAIN MOTORS.

The power equipment of each motor coach consists of four D.C. series-wound interpole motors, two being mounted on each of the two bogies of the coach. Each pair of motors is permanently connected in series to operate from the 1,500 volt line so that, while individual motors are wound for 750 volts, all are insulated to withstand 1,500 volts to earth. The motors are rated at 328 h.p., 675 volts (average line pressure being assumed as 1,350 volts) on temperature rise limits in accordance with British Engineering Standards Specification No. 173/1928.

As the motors are required to run up to very high speeds, corresponding to a specified track speed of 70 miles per hour, their mechanical design has received special consideration, and is particularly robust. The armature laminations are mounted on a steel spider, a construction allowing of easy withdrawal of the shaft, while the commutator is mounted on an extension of the spider so that, when the shaft is withdrawn, the commutator, core and winding remain undisturbed in relation to each other. The armature of the motor runs in sleeve bearings lubricated on a patented system whereby the principal deficiency of the well-known "oil and wool waste" method of lubrication is eliminated. In this system oil is lifted from the save-oil chamber by means of a pneumatically operated injector* connected to the compressed air supply of the train. The process of lifting the oil is effected when the coach is taken out of service at night or before it starts in the morning, the injection system being completely isolated from the compressed air supply during service by a suitable cock. Oil which has passed through the bearing into the save-oil chamber is returned to the main reservoir on that side of the bearing where feed oil is contained. As the oil from this point is conveyed through a wick, any grit or impurities which may have been introduced are prevented from reaching the bearings.

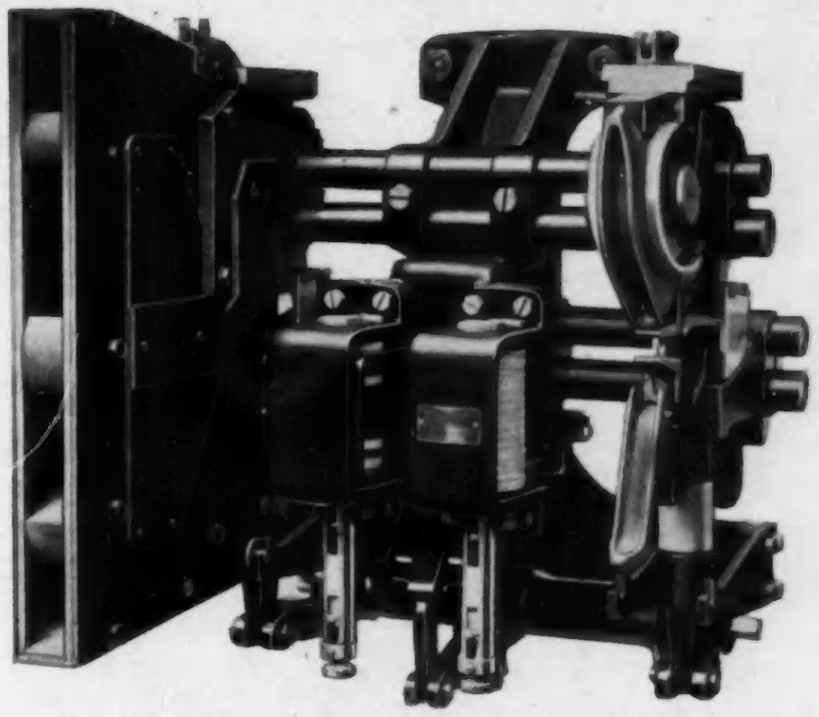

Fig. 6.—Main 1,500-volt D.C. circuit breaker.

Fig. 5.—The pantographs are designed to maintain an even pressure on the overhead line at all the varying heights along the track.

The insulation of the motor is mainly of mica, cotton being used only in positions remote from the actual conductors. A double fan ensures a positive air stream through the core of the armature, over its

* Patent No. 320,560.

periphery and between the field coils. One of the motors is illustrated in fig. 3, and a view of a motor coach bogie is shown in fig. 4.

### POWER CIRCUITS.

The 1,500 volt current supply for the motors is collected from the overhead line by pantographs of special design (fig. 5), capable of collecting full load current at maximum speed without harmful sparking. The pantographs are designed to maintain an approximately even pressure on the overhead line at all the varying heights occurring along the track. The inertia of the moving parts of the pantograph are reduced as far as is practicable. This is a feature of considerable importance, for on this particular line there are a large number of low bridges, necessitating frequent change in the height of the overhead line.

A push button situated behind the driver in the driving cab of each motor coach, operates the pantograph valve and a master switch provides remote control of all the pantographs on a train as soon as one pantograph is raised. A hand pump is also fitted for raising the pantograph when the compressed air supply is not available.

Adjacent to the pantograph are mounted on the roof, a main fuse for the protection of the complete equipment, a lightning arrestor of the "condenser and gap" type and a choke coil. The current is conducted through a roof insulator and is directly led to the equipment earthing switch, which is automatically earthed before the equipment can be handled for maintenance or inspection. Directly following this switch is the main circuit breaker which controls all 1,500 volt circuits fed from the pantograph. From the ground side of the circuit breaker, the feed is branched for the main motor circuits and for the auxiliary circuits. The main circuit breaker is capable of rupturing any short-circuit current to which it may be subjected. Its construction consists of two special contactors connected in series, each operating in a separate arc chute provided with extensions built into the equipment framework of the coach.

The circuit breakers are arranged for individual hand setting, but apart from the normal overload trip mechanism, remote control tripping is arranged so that a driver may trip all breakers on the train from his driving position in case of emergency. In fig. 6 is shown a circuit breaker with one arc chute removed,

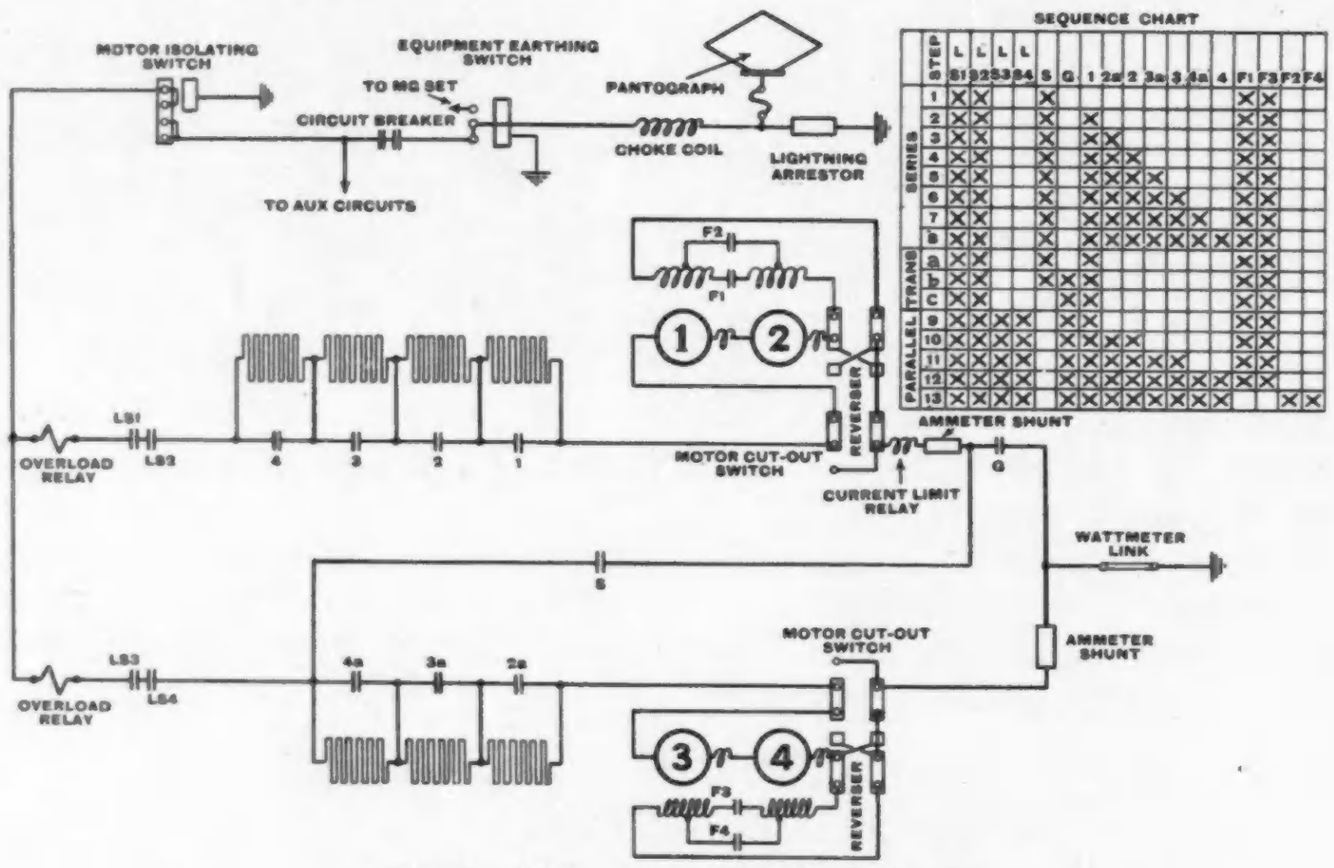


**Fig. 7.—Main power circuit diagram.**

It should be noted here in connection with the earthing and isolating switches, that interlocking features are incorporated to give complete safety to inspecting and maintenance personnel, access to the 1,500 volt apparatus being obtainable only when it is isolated from the 1,500 volt supply and earthed.

All high tension apparatus on the motor coaches is situated in an apparatus compartment immediately behind the driver's compartment, the apparatus compartment having an inner chamber which contains the whole of the high tension apparatus for the auxiliary circuits, that is, the 1,500 volt control apparatus for the heater circuits, compressors and motor-generators. Thus, by the interlocking provided, an inspector can enter the outer compartment for inspection of the main power equipment, while keeping the auxiliary equipment under tension so that compressed air and low tension supply are available for lighting and testing. This provision is necessary as it was desired to avoid the use of

batteries. The inner high tension chamber can be entered only when the whole equipment is definitely isolated and earthed.

This safety interlocking is carried out in the following manner. The door giving access to the outer chamber can only be unlocked by the "reverse" key taken from the master controller. The unlocking of the door disconnects all motor circuits from the pantograph and earths them through the agency of a drum type motor isolating switch. As soon as the door is opened this switch is locked into the isolating position from which it cannot be moved until the door is again closed.

The isolating switch itself is situated in the inner high tension chamber, as one of its terminals remains alive so long as the auxiliaries are energized. Protection is accordingly afforded not only by isolation, but also by the equipment effected being earthed.

Access to apparatus in the inner high tension chamber is possible only by the use of the control switch operating key, the removal of which from the control switch necessarily shuts off the control supply to all auxiliaries. The key is used to operate

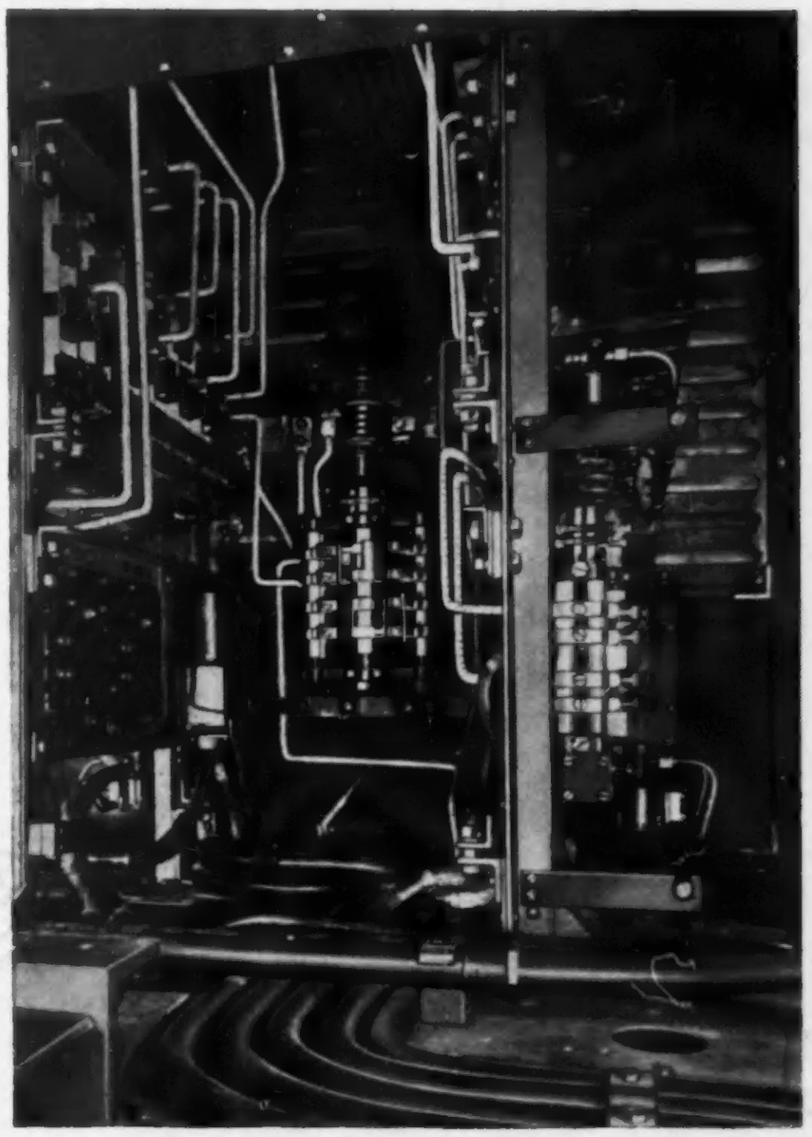

Fig. 8.—Interior of high tension chamber showing 1,500-volt control gear.

a special double lock mounted on the panel at the rear of the driver. By moving the first lock from the normal running position to the "dead" position, the pantograph is exhausted and disconnected from the air supply; consequently it falls. The key is then removed and the second lock moved to the "dead" position, unlocking the main interlock mechanism and permitting a handwheel on this mechanism to be moved to the "dead" position, thereby earthing the pantograph and enabling the covers of the inner high tension chamber to be removed. The removal of the covers locks the interlocking mechanism, so that it cannot be returned to the "live" position, the removal of any one cover being sufficient to prevent this. The main interlocking mechanism also operates through

Fig. 9.—1,500-volt electro-pneumatic contactor with arc shield removed.

the roof to prevent access being gained to the main fuse unless the pantograph has been lowered. It will be seen, therefore, that the interlocking provided affords a very complete measure of safety.

Returning to the main power circuit, fig. 7, the feed from the isolating switch passes through the overload relays, the line switches, resistances, reversers, motor isolating switches, and field tap switches. This apparatus, with the exception of the pantograph main fuse, lightning arrestor equipment and motor isolating switches, is mounted on a duplex framework, the centre portion of which is shown in fig. 8. On the left may be seen one set of contactors, relays, etc., while on the right is the second set. The drum type motor cut out switch and the current limit relay can be seen at the back of the central space, while higher up the frame are mounted the main resistances, the under sides of which can just be seen.

The contactors employed, fig. 9, are of the electro-pneumatic type and are specially designed for the requirements of 1,500 volt working. The contacts are operated by compressed air cylinders, the

admission and release of air to which are controlled by small solenoid-operated valves. The valve-operating coils being of relatively small capacity, the control currents are in consequence more easily dealt with than they would be with an "all-electric"

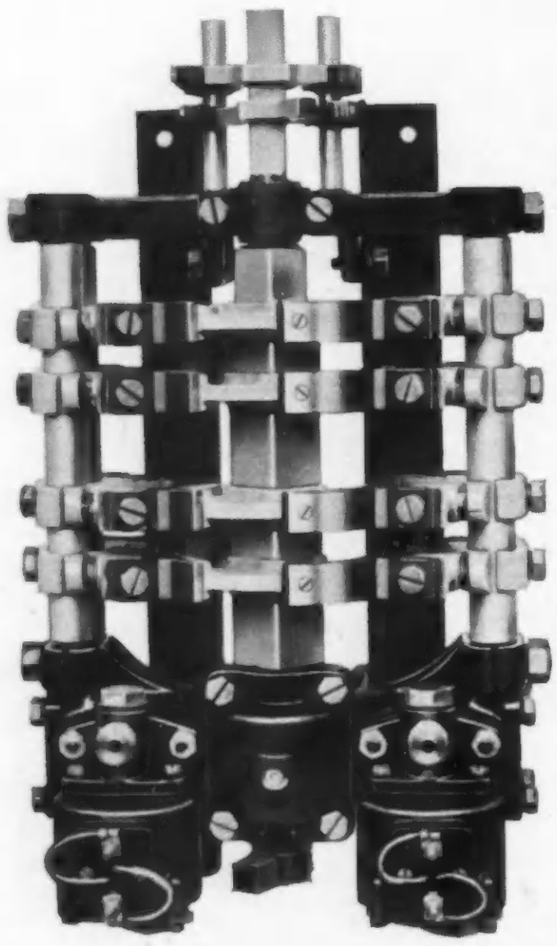

**Fig. 10.—1,500-volt electro-pneumatic reverser.**

The powerful closing pressure obtained by the use of compressed air allows a heavy return spring to be provided for opening the contactor, thus avoiding the risk of "welding in." Loss of air past the piston is obviated by a special construction in which the piston at the end of its stroke definitely seals the whole chamber by butt contact against a leather washer.

The reverser, fig. 10, is in the form of a drum switch and is operated by a 2-cylinder air engine. Solenoid operated valves control the admission of air to one or other of the cylinders, thus moving the reverser to the "forward" or "reverse" position as required by the driver. Suitable electrical interlocks are provided so that the main circuits cannot be completed unless the reverser has been thrown fully to the direction of rotation corresponding to the master controller.

It is not possible in this article to describe in detail all the main circuit apparatus, but the following brief remarks will be of interest.

The two overload relays, and the current limit relay for automatic acceleration are all similar in design, each being of simple but robust construction. The relays are mounted on a large bakelite base, the discs, contacts and fingers on all the relays being interchangeable. Particular attention has been paid to the insulation of the 1,500 volt circuits to earth and between the low and high tension circuits. The

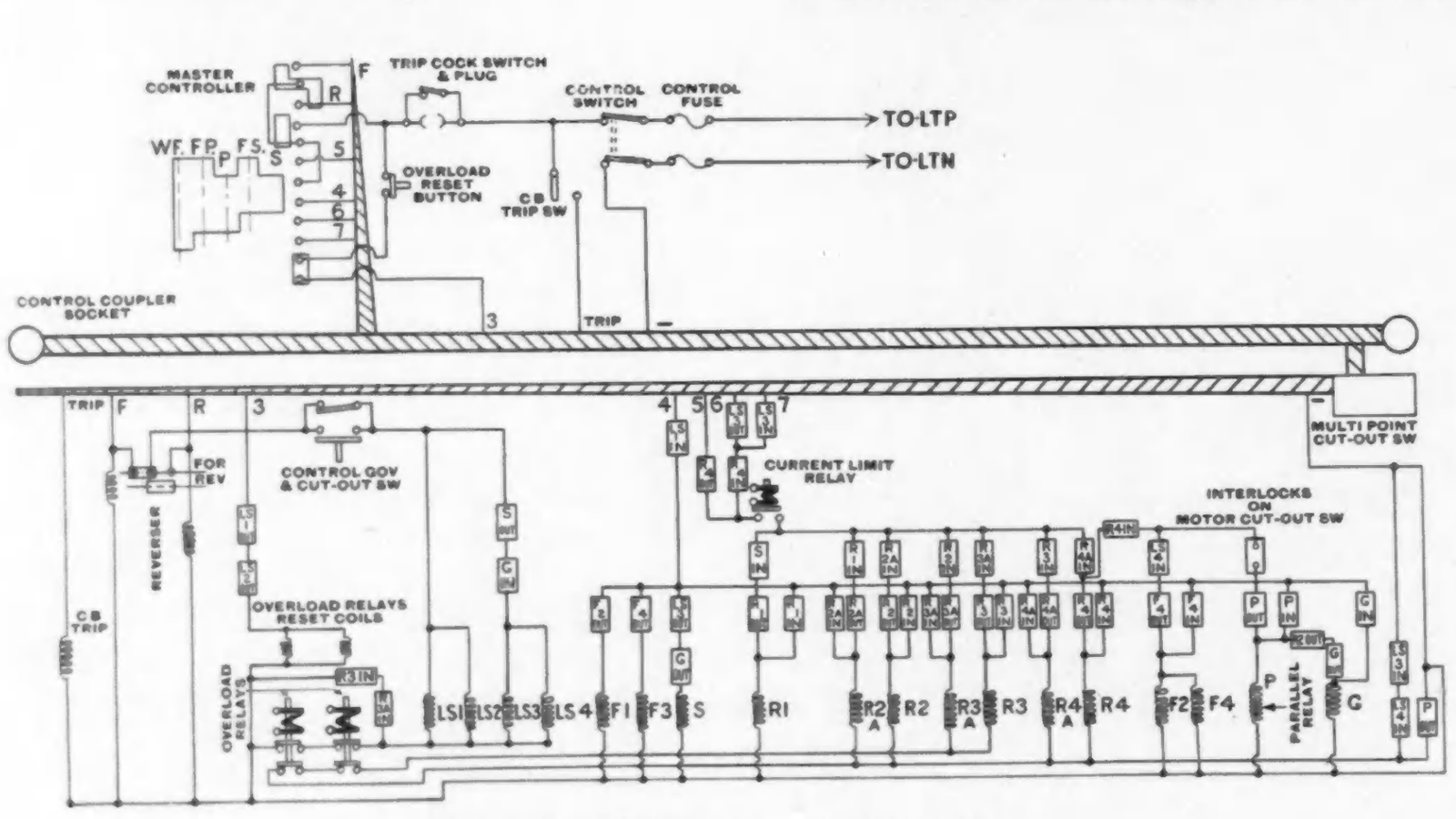


**Fig. 11.—Diagram of control circuits.**

equipment. Energisation of a valve-solenoid admits air to a piston which is forced upward against a strong return spring and closes the contact jaws. The jaws are provided with the usual "knuckling" feature, introducing a wiping action and ensuring clean contactor tips.

overload relay latches itself up when tripped by overload, and can only be reset by means of a push button in each driver's cab when the master controller is in the "off" position.

A simple form of drum switch allows either pair of motors to be cut out, while interlocks on the same

switch make the necessary changes in the control circuits.

As will be seen from fig. 7, shunt transition is employed, and the motors are arranged for one step of field tapping.

The main resistances are provided with double insulation, and careful consideration has been given to the ventilation of the H.T. chamber in which the resistances are situated in order to ensure proper dissipation of the heat generated.

It may be interesting briefly to note the method in which transition is effected. Assuming the motors to be in full series with all resistances cut out the current flows through line switches LS1 and LS2; contactors 4, 3, 2 and 1; motors 1 and 2; contactors S, 4A, 3A, 2A; and motors 3 and 4. The first step in transition is to reinsert the necessary resistance for parallel running by opening contactors 2, 3, 4, 2A, 3A and 4A. Immediately these open, contactor G closes and places motors 1 and 2 in parallel connection. The closing of contactor G opens contactor S; contactors LS3 and 4 then close,

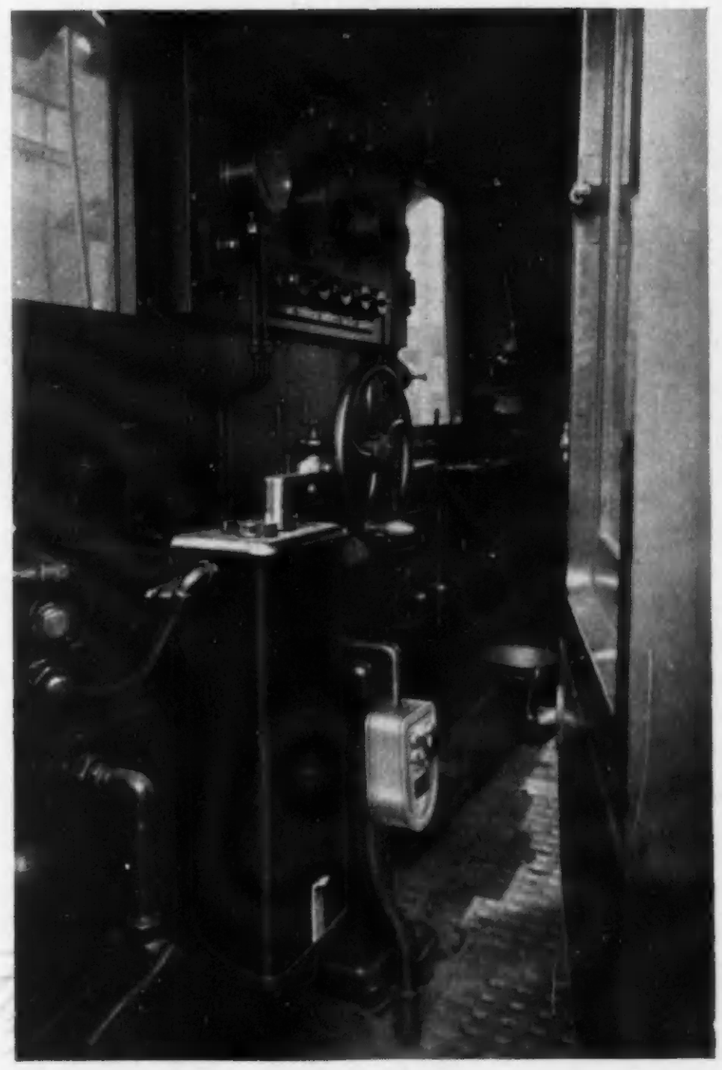

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**Fig. 12.—Driver's cabin showing master controller, brake valve and instruments.**

and the whole equipment is in parallel. These actions all take place in less than one second.

### CONTROL CIRCUITS.

The control circuits are shown in simplified form in fig. 11. It should be explained that "L.S.I. in" means that the circuit is completed when L.S.I. contactor is closed; similarly "L.S.4. out" means that the circuit is formed when L.S.4 contactor is open.

The various control circuits are connected up between coaches by means of special couplers.

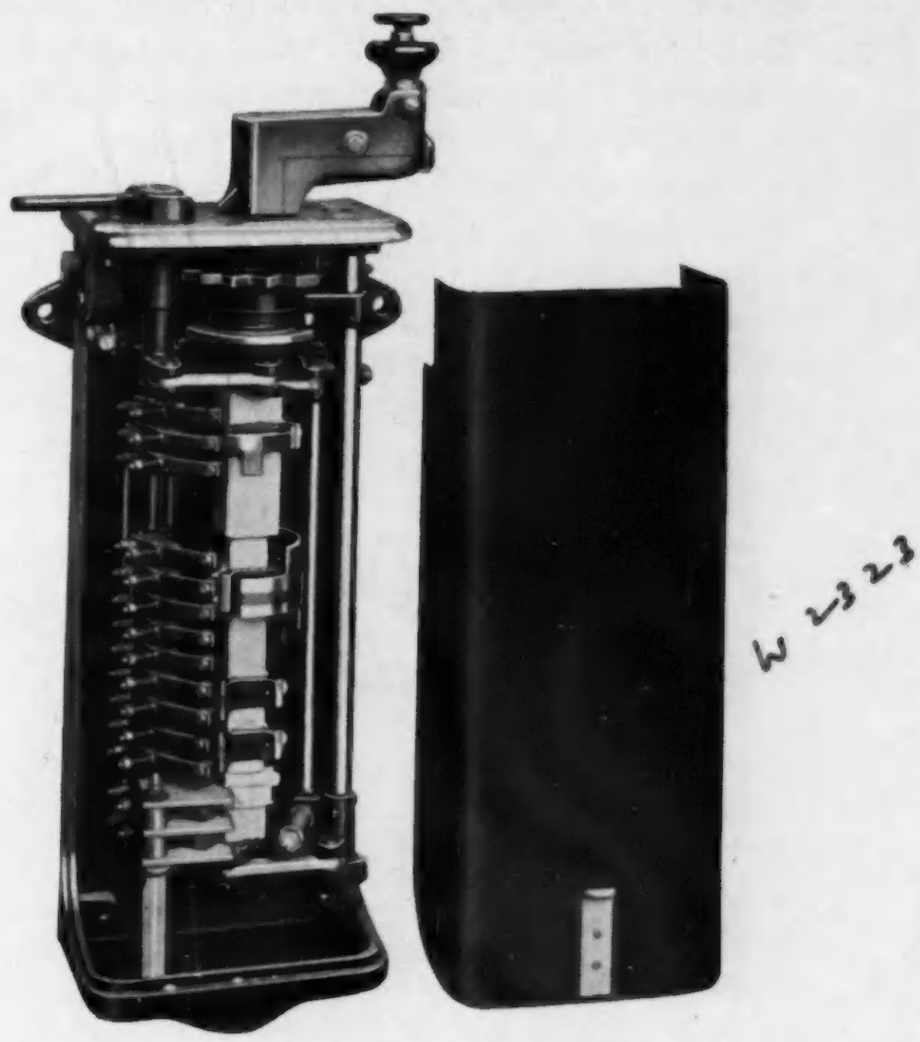

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**Fig. 13.—Interior of master controller.**

In the driver's cabin, fig. 12, is installed the master controller which is fitted with the usual dead man's mechanism. The illustration, fig. 13, clearly shows the simplicity of its construction. Immediately in front of the driver is situated the driver's brake valve and overload reset button, while the control switch, main motor ammeters, duplex brake gauge, air gauge for the control air system, and sundry lighting switches are mounted on a panel to the right of the driver. The pantograph relay is placed on the extreme right of the cab as this seldom requires to be set by hand.

### AUXILIARY CIRCUITS.

The auxiliary circuits are particularly interesting and have received much careful consideration. As already indicated, the feed for the auxiliary circuits is taken from the negative side of the main circuit breaker. From there it is led through a special 1,500-volt cartridge fuse and, before branching to the compressor and motor-generator set, passes through a small protective resistance which functions as a limit resistance in the event of a short circuit. The ohmic value of this resistance is too low to have an appreciable effect under ordinary working conditions.

The compressor is of the reciprocating type and is mounted beneath the car frame. Its 1,500-volt driving motor is controlled directly by means of a single contactor operated from the master governor, the circuit being protected by a separate 1,500-volt fuse. The master circuits are so arranged that normally all compressors of a train are synchronized when operating. Actually one compressor is sufficient for the requirements of a normal train, and any compressor can be separately isolated.

The second branch of the auxiliary high tension circuit passes through a high-tension fuse to the motor-generator. The motor-generator has a capacity of 12 kW and supplies low tension current for control and lighting at approximately 110 volts, and has sufficient capacity to supply a six-coach train.

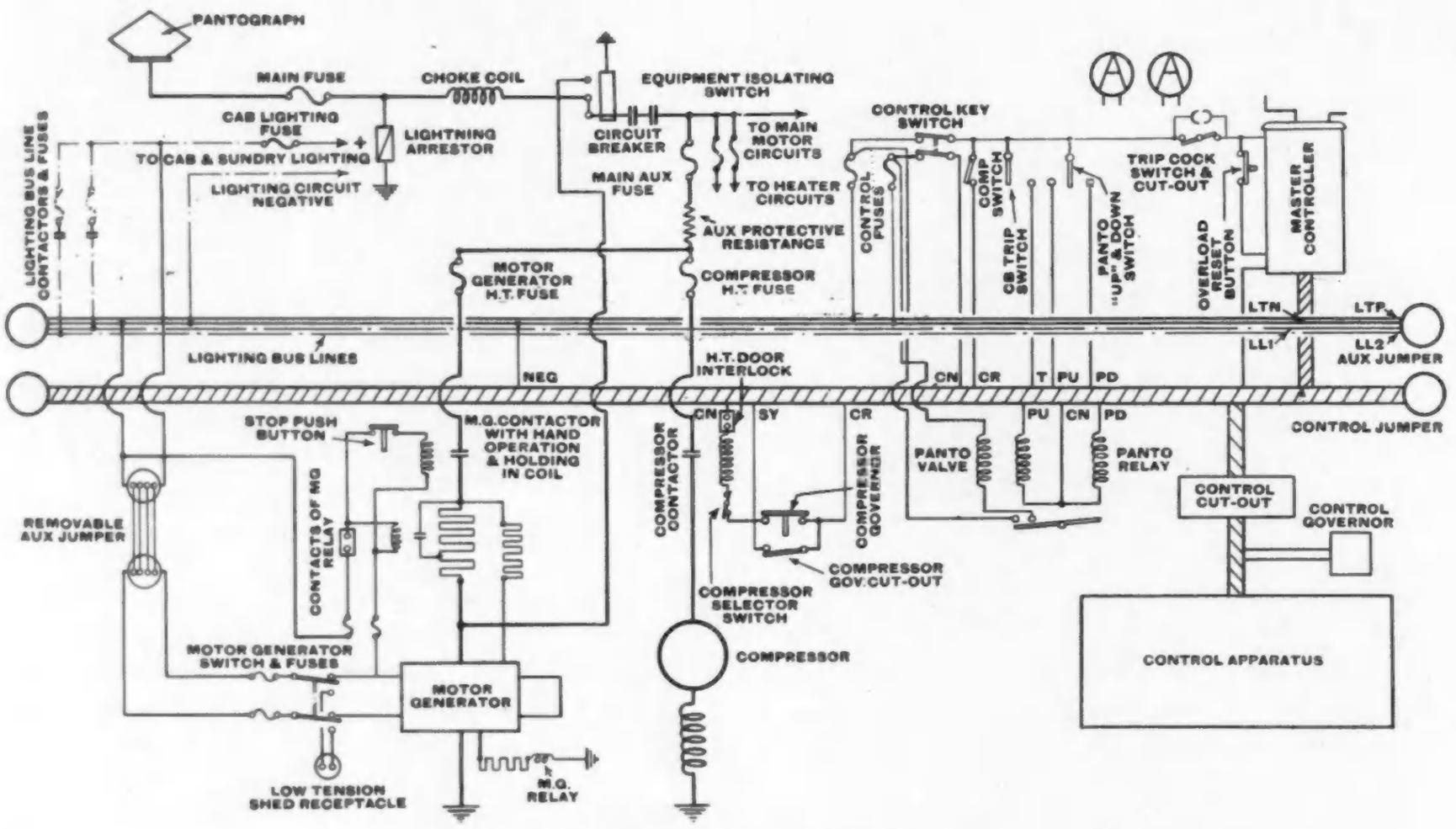



**Fig. 14.—Diagram of auxiliary circuits.**

The machines are started and stopped by means of a push button situated immediately behind the driver, a partially automatic starting step being provided. The auxiliary circuits are shown in simplified form in fig. 14.

### HEATING CIRCUITS.

The heating circuits are of special interest. Each compartment is provided with four 300 watt heaters each of which is insulated for 1,500 volts to earth and wound for 750 volts, two heaters being permanently wired in series. Two heating circuits are provided on each coach, remote-controlled by contactors which are energized by master switches situated in the guard's compartment. These switches operate contactors situated in the high tension chambers. Each local circuit is provided with special 1,500-volt cartridge fuses enclosed in cast iron containers mounted on the ends of the coaches, while main heater circuit fuses are provided in the inner high tension chambers of the motor coaches. Special 1,500-volt jumpers are provided for carrying the high tension supply to the heaters in the trailer and driving trailer cars, and by means of a patented system of interlocked couplers, the withdrawal of a coupler is rendered impossible at any time when either it is carrying current or is energised at 1,500 volts. This safety feature is necessary in order to avoid danger to the shunting personnel when making up trains.

### LIGHTING.

Lighting is carried out at 110 volts, supply being taken from the motor-generator sets. The circuit on each coach is divided into two main branches, so that either one half or the full number of lights may be employed. The lighting circuits may be all fed from a single motor-generator set, or alternatively may be distributed among the various motor generator sets on the train. Whatever arrangement is employed, however, it is impossible to parallel the motor-generator sets. Master control of all lighting circuits is effected from the guard's compartment.

In conclusion, acknowledgment must be made to Lt. Col. Cortez-Leigh, M.Inst.C.E., M.I.E.E., Chief Electrical Engineer to the L.M.S. Railway, and to H. N. Gresley, Esq., C.B.E., M.I.E.E., Chief Mechanical Engineer to the L. & N. E. Railway, who were jointly responsible for the complete electrification and the supervision of the equipment during manufacture.

# Discharge Tubes and their Technical Applications.

## PART III.—APPLICATIONS AND METHODS OF MANUFACTURE.

By N. L. HARRIS, B.Sc., A.Inst.P., and H. G. JENKINS, M.Sc., A.Inst.P.

Research Laboratories of The General Electric Co., Ltd.,
Wembley, England.

*Parts* I. *and* II. *of this article* (*G.E.C. Journal, Vol. 2., No. 1, May,* 1931) *gave an historical account of the development of discharge tubes and of their relationship to modern theories of atomic processes, together with a brief account of phenomena occurring within the discharge between cold electrodes.*

*In Part* III. *the authors describe the practical applications of discharge tubes and methods of manufacture. Cold cathode tubes are first dealt with, special mention being made of the development of these tubes for advertising and display purposes. Subsequently, hot cathode discharge tubes are considered, with special reference to important developments which have recently been made in this field.*

IN the concluding part of this article, it is proposed to give an account of the practical applications of gas discharge tubes. For this purpose the various types will be grouped conveniently as follows :—

(*a*) Negative glow tubes.
(*b*) Positive column tubes.
(*c*) Hot cathode tubes.

It must be realized, however, that this is a somewhat arbitrary classification, and the different types are not so sharply differentiated as this division would imply. An exhaustive description of every type of tube does not fall within the scope of this article, but an endeavour has been made to cover all the important applications.

### (12)—MANUFACTURE OF SMALL DISCHARGE TUBES.

A very brief account of the methods of manufacture of small negative glow tubes may be of interest, and it should be realized that the principles embodied in these processes apply to the preparation of most types of discharge tube.

The electrodes are usually shaped from nickel or iron, and before assembly are placed in a vacuum furnace, which is exhausted to a low pressure. The furnace and its contents are then raised to a red heat, when the gases occluded in the metal electrodes are released and pumped away. If this were not done, these gases would be liberated during the life of the discharge tube, and would contaminate the gas in which the glow takes place, thereby altering the colour and characteristics of the discharge.

The vacuum-furnaced electrodes are mounted on a "pinch" and sealed into a glass bulb in the usual way, the process resembling that employed in the manufacture of lamps and valves. In some tubes, where, for example, high operating potentials are required, it is not possible to mount the electrode system on one support and the electrodes are sealed individually into the glass envelope by hand. A glass stemming tube is either sealed into the bulb, or incorporated in the pinch, so that the discharge tube may be connected to the pumping system. The latter usually consists of a high speed mercury vapour pump capable of exhausting to a pressure of $10^{-6}$ mm. of mercury, or less, together with an oven in which the tubes are baked to free the glass from water vapour and other gases which would contaminate the tube during life unless removed during manufacture.

Reservoirs of various gases such as neon, argon, helium, hydrogen, etc., are connected to the pump system, together with purifying devices and pressure gauges, so that the tubes may be filled with any gas required at a given pressure. Direct and alternating current electrical supplies at potentials up to 1,000 volts or so are available for glowing the tubes.

When the process of exhaustion and baking is complete, the tube is filled with gas at a few mm. pressure, and a heavy discharge passed to heat the electrodes and free them from the last traces of occluded gaseous impurities. The contaminated gas

is pumped away, and the tube refilled to the desired pressure, after which it is sealed off ready for capping. It has already been mentioned (Section 6, Vol. II., No. 1, page 11) that a series resistance is required to stabilize the discharge, and this frequently takes the form of a small spool wound with fine resistance wire and incorporated in the base of the lamp. A resistance of some thousands of ohms is usually needed, the exact value being chosen to stabilize the discharge current at the required value for a given applied potential.

**Fig. 10.—Osglim "beehive" and "letter" lamps.**

### (13)—THE USE OF NEGATIVE GLOW TUBES AS ILLUMINANTS.

Negative glow tubes are defined as those in which the electrodes are close together, the light emitted coming principally from the negative glow, while the visible positive column and the anode glow are usually entirely absent. Under "normal" discharge conditions the cathode is incompletely covered by the discharge and the area of glow, and therefore the light output from the tube is directly proportional to the current passing. Tubes with long slender cathodes, operating on this principle, were used in early experiments on sound film recording, the area of electrode covered with glow following closely the fluctuations of input current from the microphone amplifier.

Under "abnormal" discharge conditions, when the cathode is completely covered by the discharge, the brightness of the glow increases with increasing discharge current, and is again proportional to this latter. The relation between discharge current and applied voltage is linear over a considerable part of the range of abnormal cathode fall of potential (*cd*, fig. 5, Vol. II., No. 1, page 11). The light output, $L$, per watt will then be inversely proportional to the applied potential $E$,

$$\text{for } L = kI/EI = \frac{k}{E} \qquad (11)$$

and the lower the potential on which the lamp can be operated, the better will its efficiency be.

A neon or neon-helium gas filling is usually adopted for lamps of this class, partly on account of the low striking voltage possible compared with other gases or mixtures of gases, and also because of the comparatively high luminous efficiency. They are generally made for operation on 200–250 volt supplies. The light emitted is a warm orange red, and the luminous efficiency amounts to about 1.2 lumens per watt, corresponding to about 10 watts per candle. "Osglim" lamps of this type are illustrated in figs. 10 and 11. They consume 5 and 0.5 watts respectively, and are used as low power illuminants and indicators to show whether a circuit is "live" or "dead," or, in wavemeters, to indicate when the tuning is exact. The D.C. striking potential is about 180 volts, and the extinguishing potential some 40 volts lower. By special treatment of the electrodes and modification of the gas filling, the striking potential of lamps of this class can be reduced to a value of approximately 90 volts.

**Fig. 11.—Osglim indicator lamp.**

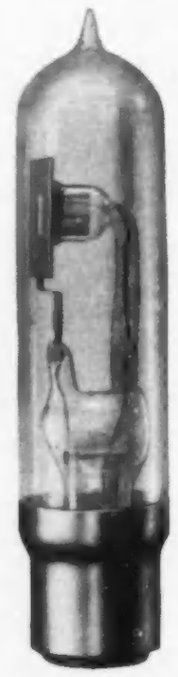


**Fig. 12.—Hilger discharge tube, a type of negative glow tube giving a concentrated source of radiation suitable for spectroscopic work.**

Fig. 12 shows a type of negative glow tube in which the discharge is confined within a small U-shaped electrode giving a concentrated source of radiation suitable for spectroscopic work. These tubes were developed in the Research Laboratories of The General Electric Company, England, and are

marketed by Messrs. Adam Hilger, Ltd. The gas fillings available include the rare gases, hydrogen, nitrogen, oxygen, carbon dioxide, etc., and the tubes can be fitted with a quartz window to allow the passage of the ultra-violet radiation in the discharge.

Neon-filled negative glow tubes have recently been used by the Cambridge Instrument Company as standards of temperature for use with the disappearing filament pyrometer. The brightness of

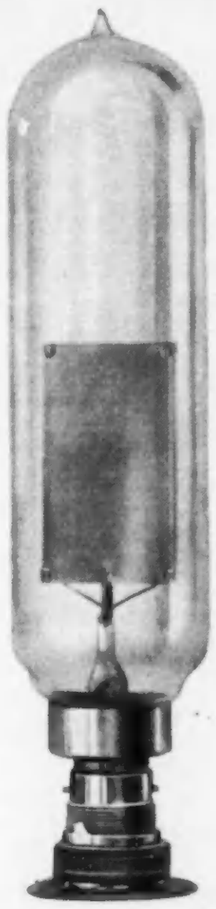


**Fig. 13.—Osglim television lamp, as used in certain television receivers, the cathode being a flat plate backed with mica.**

the glow (*i.e.* the "temperature") remains constant for a given discharge current, while the red colour of the glow greatly assists the eye in adjusting the pyrometer.

Fig. 13 illustrates the type of Osglim lamp, used in certain television receivers, in which the

**Fig. 14.—Osram D-1 recording tube, as used in systems of sound film recording and picture telegraphy.**

cathode is a flat plate backed with mica. The whole of the front surface of the plate is covered with a uniform neon glow which is modulated by the television signal. A rotating scanning disc, pierced with a series of small holes, is mounted in front of the plate, so that at any moment the eye is viewing only a very small portion of the glow, the instantaneous intensity of which is appropriate to that particular element of the picture. An image approximately the full size of the plate is built up as the glow is scanned.

Other television systems employ "crater" types of discharge tube, in which an intense glow is confined to a small crater and is projected by an optical system to scan a screen. The glow is modulated by the television signal, and at any instant its brilliance is appropriate to that element

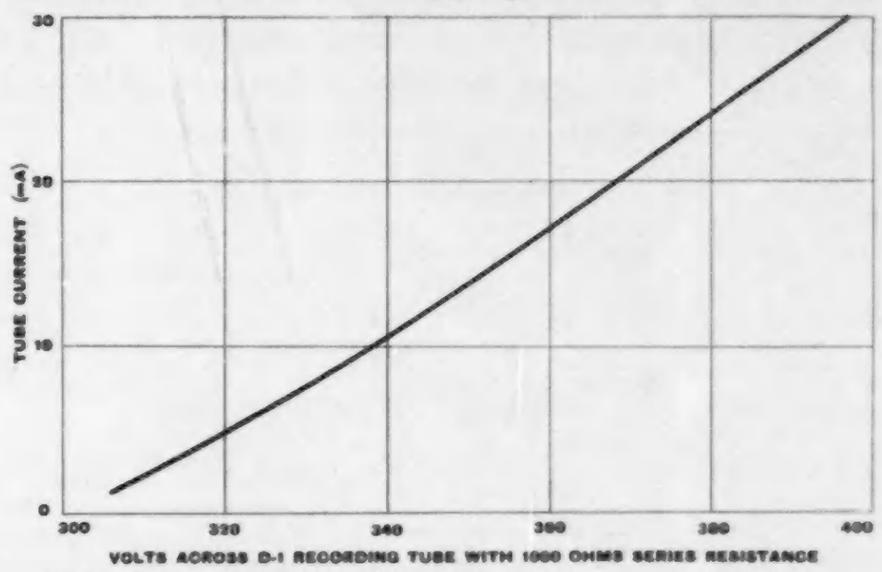



**Fig. 15.—Typical recording tube current-voltage characteristic.**

of the picture on the screen where the spot is resting momentarily.

Use is also made of this type of tube in certain systems of sound film recording. The modulated glow is projected by a suitable optical system through a very fine slit on to the moving film, and the sound is recorded as variations in density along the length of the track. A similar method is employed in certain systems of picture telegraphy. The neon glow, although bright to the eye is comparatively non-actinic photographically, and argon, helium nitrogen or mercury vapour gas fillings are chosen because of their greater photographic activity. Two types of tube are made. In the first (somewhat akin to the spectroscopic tube of fig. 12) the glow is a true negative glow, confined to a crater, the walls of which may be coated with thermionically active compounds of barium, strontium, etc., to increase the discharge current and so enhance the brilliancy of the glow. A second type, shown in fig. 14, is filled with a neon-mercury mixture, and employs a short positive column within the inner tube as the source of a highly actinic bluish-white light. A special feature of this tube, as developed in the Research Laboratories of The General Electric Company, is the small "point" anode which ensures the absence of parasitic noises and oscillations within the discharge. This is essential to good sound recording. A typical current-voltage characteristic is given in fig. 15. The tube is designed to operate in the anode circuit of a valve of the LS.5 class, in the final stage of the voice-frequency amplifier, with an overall applied potential of 700 volts. The discharge strikes at this potential

and the voltage is then shared between the valve and the discharge tube, the steady current being 15 mA. Tubes for currents of 30 mA. are also made.

The gas discharge is ideal for modulation purposes, since it is free from the inertia and resonances which are almost unavoidable in any mechanical system. Frequencies of 15,000 or more cycles per second can readily be recorded by its aid.

**(14)—DISCHARGE TUBES AS PROTECTIVE DEVICES.**

The property that a discharge tube possesses, in virtue of which it remains effectively non-conducting

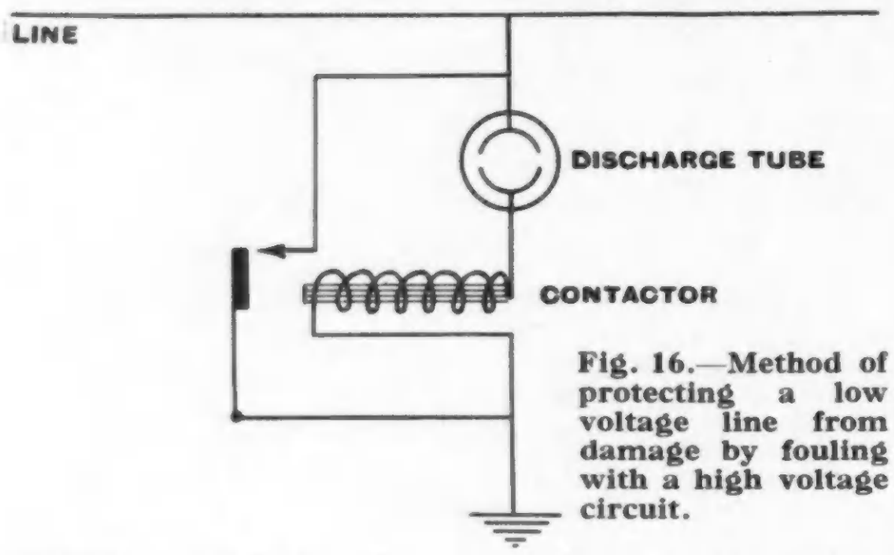



**Fig. 16.—Method of protecting a low voltage line from damage by fouling with a high voltage circuit.**

until the applied voltage reaches a definite value, namely, the striking potential, permits of its use as a protective device in various circuits. Connected across an inductance or a transformer winding it protects the insulation from high voltages by flashing over when dangerous surges occur.

Fig. 16 illustrates an arrangement adopted to protect a low voltage line and its associated gear from damage by fouling with a high voltage circuit. The striking potential of the discharge tube is made greater than the voltage of the normal line, but if a high potential line comes into contact with the latter, the tube strikes and a heavy current passes through the contactor, earthing the line and pulling out the main breakers. At the same time the discharge tube is short circuited, so that it is not called upon to pass heavy currents for long periods.

A device for protecting a circuit from a small voltage rise is illustrated in fig. 17. The striking potential of the discharge tube is arranged to be a few volts above normal line voltage, so that any surge in the supply causes a heavy current to pass through the tube, and disconnects the local circuit by operating the trip coil of the circuit breaker.

The requirements of a constant striking potential, low internal resistance, and high current carrying capacity in tubes of this type are met by using heavy electrodes, carefully gas-freed, and set close together. A tube designed to strike at 150 volts, and capable of passing 50 amperes for 0.025 seconds, is illustrated in fig. 18.

Small tubes designed on similar principles have been used to protect telephone lines, etc., from charges induced by atmospheric electricity and from lightning. The electrodes are sometimes coated with sodium or potassium, so that the discharge shall rapidly pass into an arc and so dissipate the accumulated charge more quickly.

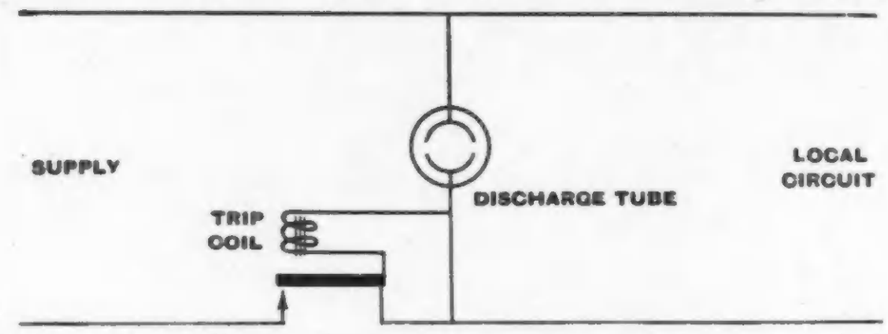



**Fig. 17.—Method of protecting a circuit from a small voltage rise.**

**(15)—VOLTAGE REGULATORS AND REDUCERS.**

It has already been shown (Section 6) that so long as a discharge tube operates under "normal" conditions, the voltage across it remains at an almost constant value for changing currents. If the electrodes are close together, this constant potential is a little above the normal cathode fall for the gas filling employed. Under these conditions the tube may be used on a high voltage D.C. supply (say 200 volts) to provide a source of low potential (say 20–40 volts), which remains unchanged with varying load on the circuit (fig. 19).

On the other hand, the tube may be used in parallel with some high resistance load, the combination being connected, with a suitable series resistance across the D.C. mains. Providing the tube operates

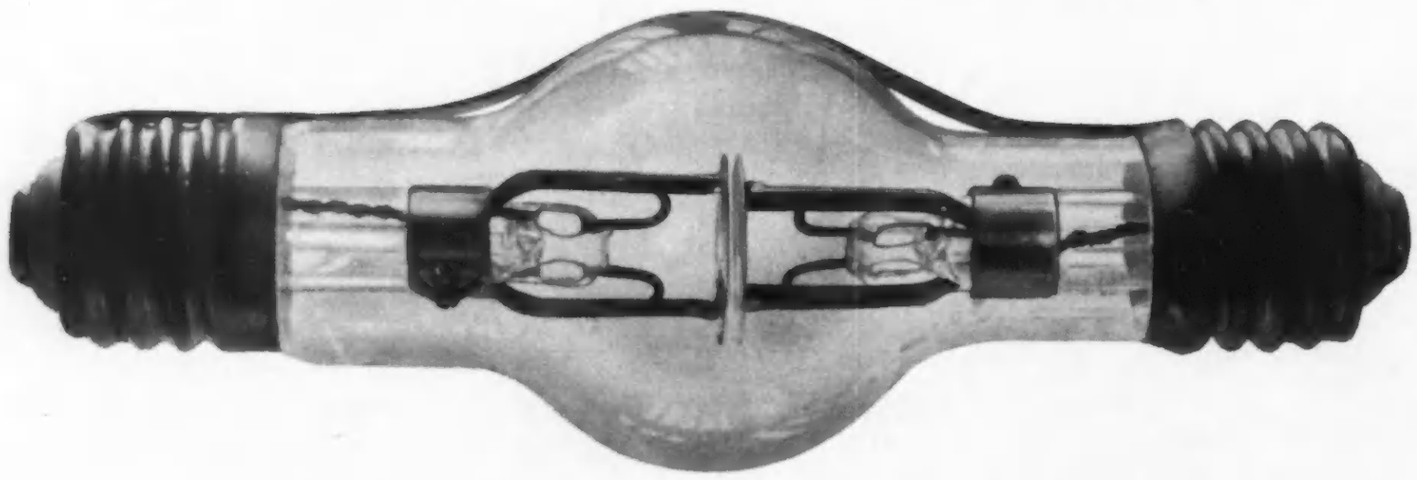


**Fig. 18.—Osram earthing valve, capable of passing 50 amps. for 0.025 sec.**

throughout under "normal" conditions, fluctuations in the supply are smoothed out, and an unvarying potential is applied to the local circuit (fig. 20). In both these cases a cathode of large area is required, but the anode may be relatively small.

On A.C. circuits a discharge tube can still be used as a voltage reducer, suited for example, to the operation from the normal lighting mains of bells or similar apparatus. Fig. 21 illustrates the circuit employed, and it will be seen that the bell circuit is dead until the press button is operated. The electrodes of these tubes must be of approximately equal area or, if concentric cylinders are used, dissimilar metals may

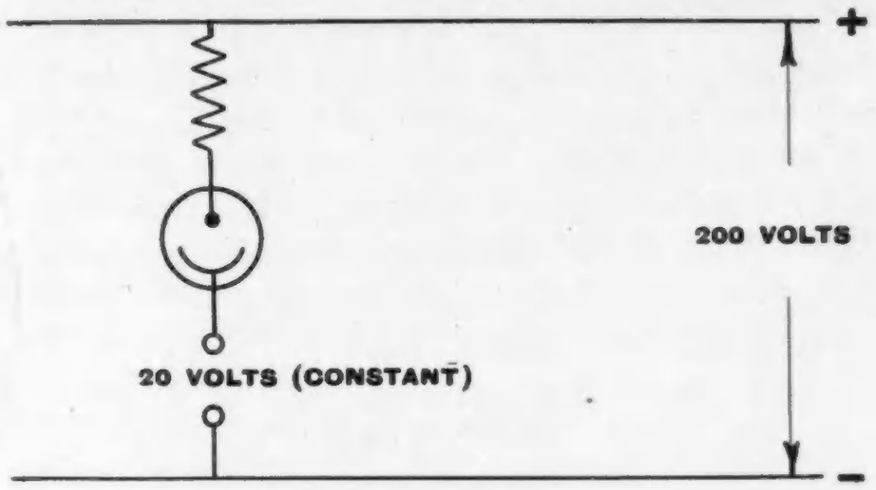



Fig. 19.—Method of providing a source of constant low potential from a high voltage D.C. supply.

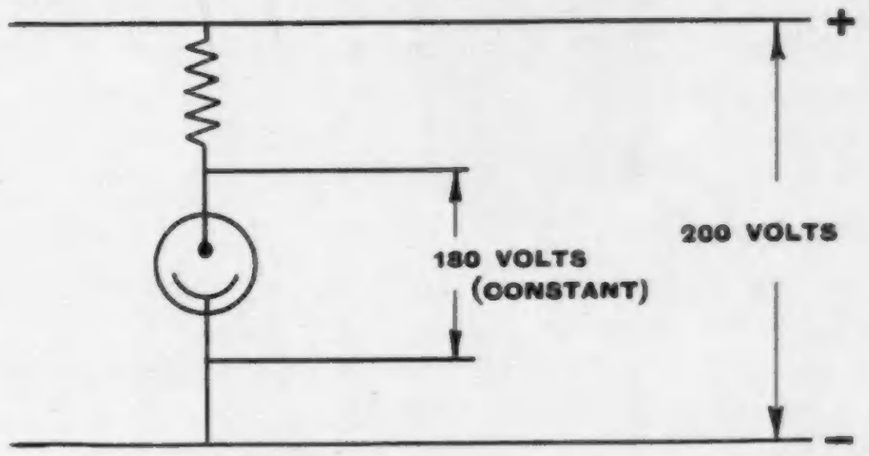



Fig. 20.—A similar method to that shown in fig. 19 for providing a constant high potential from a D.C. supply.

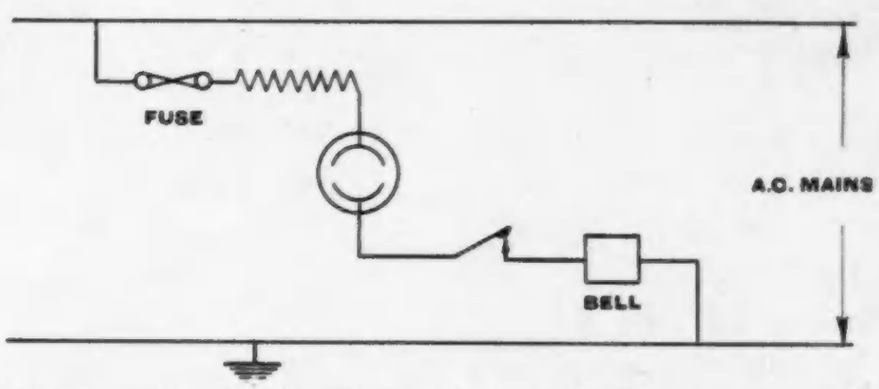



Fig. 21.—Voltage reducer circuit employing discharge tube on A.C. mains.

be employed, so that the inner electrode shall handle a greater current per unit area of surface.

**(16)—DISCHARGE TUBES USED AS RECTIFIERS.**

An expression for the mean current passing each half cycle through a discharge tube having electrodes of equal area and operating on A.C., can be derived from equation 6,

$$I = \frac{E - e}{\frac{1}{AM} + R}$$

remembering that $E = V_P \sin pt$ and that the tube is alight only throughout a portion of each half cycle (see fig. 6). With certain simplifying assumptions the value of the mean current is given by –

$$I_{Mean} = \frac{a}{\frac{1}{AM} + R} \qquad (12)$$

where $a$ can be evaluated if $V_P$, $V'_S$ and $V_E$ are known. The R.M.S. current can be calculated in a similar manner and is given by –

$$I_{R.M.S.} = \frac{\beta}{\frac{1}{AM} + R} \qquad (13)$$

where $\beta$ is a second function calculated from values of $V_P$, $V'_S$ and $V_E$. We then have, using the customary definitions –

$$\text{Form Factor} = \frac{I_{R.M.S.}}{I_{Mean}} = \frac{\beta}{a} \qquad (14)$$

$$\text{Amplitude Factor} = \frac{I_{Peak}}{I_{R.M.S.}} = \frac{V_P - e}{\beta} \qquad (15)$$

For a typical Osglim lamp operating on a 220 volt A.C. supply, it can be shown theoretically that –

Form Factor = 1·4 (approx.)
Amplitude Factor = 2.5 (approx.)

whereas for a pure sine wave the values are, respectively, 1.111 and 1.414. Similar relations, with different values of $a$ and $\beta$, also hold approximately for the case of simple rectifiers of the type described in Section 6, employing cathodes of widely dissimilar area. The current passing during alternate half cycles when the smaller electrode is cathode is considered as negligibly small. A moving coil ammeter connected in circuit will read the mean current, and a moving iron dynamometer, or hot wire meter, the R.M.S. current. The form factor in the case of the rectifier is approximately 2, and the reading of the moving coil meter will be about half that of the other. Furthermore, on account of the wave forms of the tube current and tube volts not being sinusoidal, the watts dissipated in any A.C. discharge tube cannot usually be calculated as the product of the indicated R.M.S. values of current and voltage. The tube will therefore behave as though it has a power factor less than unity, although there is no inductance present and no "lag" between current and applied voltage in the usual sense of the term.

In practice it is unusual to rely only on a difference of electrode area for the rectifying action. Since the value of the mean current depends not only on the area of the electrodes, but also on the

**Fig. 22. — Rectifying tube, capable of giving rectified currents of 50 mA. at about 150 volts.**

striking and extinguishing potentials (see equation 12), rectification may also be produced by making these potentials less in one direction than in the other. Fig. 22 shows a rectifying tube combining both principles, the large electrode being coated with a substance of low $\phi_e$ (section 5). Rectified currents of some 50 mA. at about 150 volts may be obtained.

The second principle alone is used in the hot cathode rectifier. By designing the cathode as a source of thermionic electron emission, the striking potential in one direction is made very low indeed, whilst by keeping the gas pressure low and using a non-emissive anode, that in the reverse direction is kept extremely high. At the same time the high thermionic emission from the cathode, together with neutralization of the negative space charge by positive ions from the discharge, enables large rectified currents to pass.

Tubes have been made to handle 300 amperes at 20,000 volts.

### (17)—DISCHARGE TUBES AS RELAYS.

Some uses of discharge tubes as relays in circuits where ample energy is available were outlined in Section 14. If the available input energy is very small, use can be made of a third electrode. In a simple "trigger" tube for D.C. circuits, an auxiliary electrode set near one or other main electrode, and at a free potential, will inhibit the discharge at the usual striking potential. This it does by acquiring a negative charge from high velocity electrons within the tube. If this charge is allowed to leak away through a high resistance (for example, that offered by a photocell when light falls on it) or through an ionization chamber, the discharge strikes, and a heavy current suitable for operating relays, etc., will pass. This is a true trigger action, in that the control electrode can initiate the discharge, but cannot interrupt it once it has struck. Gas discharge tubes operating on this general principle, containing a cathode, an anode and a control electrode have been named grid glow tubes, or Thyratrons.

Wider applications are obtained by operating the tube on A.C. In the circuit illustrated in fig. 23, the grid voltage is the sum of $E_A$ and $E_G$. If $E_A$ is set at a critical value, $E_G$ can be adjusted so that at a certain point of each half cycle the discharge is initiated at the grid and transferred to the anode. If $E_G$ is reversed and $E_A$ raised accordingly, the discharge can be stopped when $E_G$ exceeds a certain value. By introducing a variable phase difference between $E_G$ and $E_A$, it is possible to effect a continuous variation of the tube current by means of the grid circuit. One such arrangement in which the phase difference is controlled by the amount of light falling on a photocell is shown in fig. 24. Many applications can be found for the simple and efficient

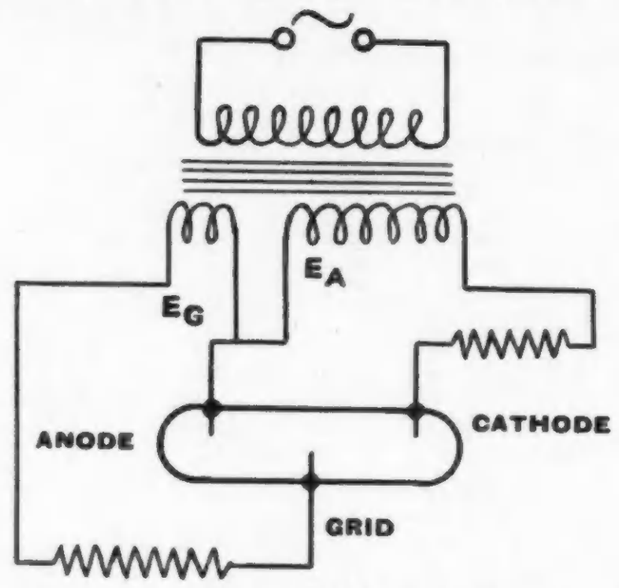



**Fig. 23.—Typical grid glow tube circuit.**

means of current control afforded by these tubes. Cold cathode tubes may be employed when currents of about 50 mA. are to be controlled, but for dealing with currents up to many amperes, hot cathode tubes, similar to the rectifiers described in Section 16 but with a third controlling electrode, are used. For exceedingly heavy duty, tubes with a mercury pool cathode are employed. Some 6,000 kilowatts can be controlled by the expenditure of 1 microwatt of energy.

The use of Thyratrons in inverter circuits may make possible the large scale distribution of D.C. power at a high voltage, by providing a means of re-transforming this directly into A.C. at the terminal station.

### (18)—LONG POSITIVE COLUMN TUBES. ("NEON" SIGNS).

The wide-spread use of "Neon" signs for advertising purposes and decorative lighting, constitutes probably the largest commercial application of discharge tubes at the present time. In addition to their use for advertising and display purposes,

cold cathode neon tubes have recently found considerable application in aerodromes as beacons, landing lines, boundary lights, obstruction and wind direction indicators, etc. This use of neon has done much to improve the safety of night flying, and most of the modern aerodromes are equipped with some form of neon lighting.

Mention has already been made of the researches of Moore on the value of discharge tubes as illuminants. The first commercial installation carried out by him in 1904 consisted of a length of 180 feet of tube filled with carbon dioxide gas to a pressure of a millimetre or so of mercury, and excited by a high voltage transformer. The luminous efficiency of a long Moore tube of this type is about 5 lumens per watt. This figure refers to the tube itself, the overall efficiency being only about half this value. Long tubes of the Moore type, both carbon dioxide and nitrogen filled, are coming into increasing use as illuminants owing to the pleasing quality of the light emitted. It seems likely that the greatly improved discharge tube technique will result in higher luminous efficiencies than those obtained by Moore with his early installations.

In addition to the long tubes used for lighting, Moore developed a compact carbon dioxide "daylight" unit for colour matching. The dimensions of these early units were 21″ × 7″ × 12″. They weighed 35 lbs., dissipated 330 watts and produced 100 foot candles immediately under the lamp. Apart from

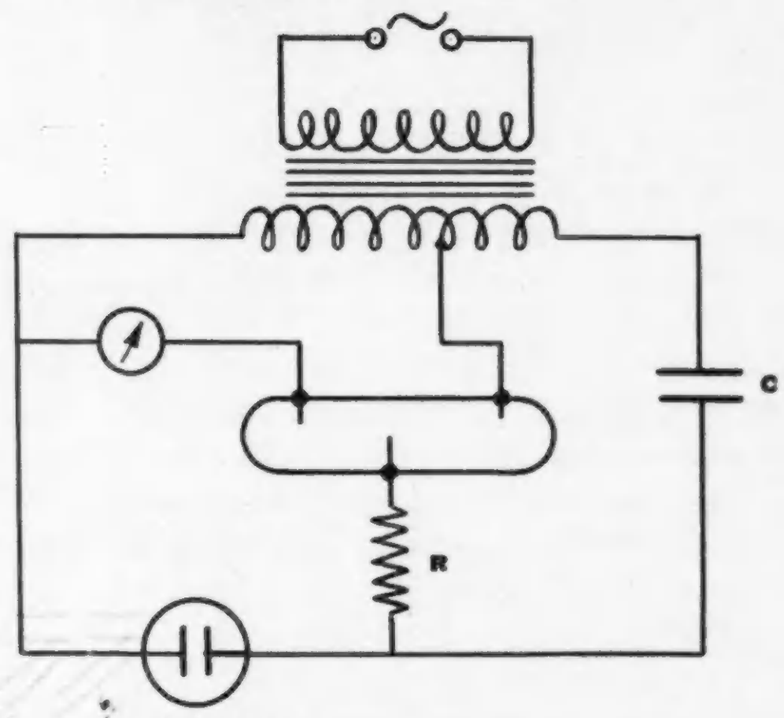



**Fig. 24.—Grid glow tube circuit with photo-cell control.**

the replenishing device, which has been greatly simplified, these daylight units were very similar to some of those being manufactured at the present day.

The next step was made by Claude in 1910, who introduced tubes containing Neon for display purposes. Owing to the rich red colour of light from these tubes, and their high luminous efficiency (about 8 to 12 lumens per watt), they are eminently suitable for advertising purposes. The development of the now familiar blue and green tubes soon followed on the use of neon. These colours are obtained by the addition of mercury to the neon tubes. Argon by itself has not been much used for advertising work, owing to its extremely low luminous efficiency. It is, however, sometimes used along with mercury for blue and green tubes. Krypton and xenon, like argon, are very inefficient. Furthermore their cost is prohibitive, and it seems unlikely that they will find much application in sign work. On the other hand, helium has an attractive whitish colour, and although it is less efficient than neon, it is much more efficient than the other rare gases. It has not, however, been much used for sign work up to the present time, on account of the rather poor life hitherto obtained from tubes filled with it. It has been a matter of some urgency to overcome this defect, owing to the increasing demand for new colours, and recent developments in technique have resulted in a form of helium tube, which gives a very satisfactory life. It seems highly likely that these tubes will soon come into more wide-spread use.

The tubing used in the manufacture of "Neon" signs must have good weathering and working properties. It is normally used in the following standard sizes:—9, 11, 15, 22, 30, 35 and 40 millimetres internal diameter. The two last named sizes are rarely used except for special work, and the 9 mm. size is used almost entirely for small shop window signs and the like. The glass benders shape the various letters and designs to drawings made on paper. Considerable skill is called for in making the bends in long lengths of large diameter tubing. Large letters and designs are bent in several sections, which are finally joined together. In order to facilitate handling of the tubes during pumping and erection, signs are usually built up from separate sections of a maximum length of about two metres. This has the additional advantage that short sections are much more readily replaced. When the main tube work is finished by the benders, the electrodes are fitted.

Various metals, such as copper, nickel, iron, etc., are used for the electrode material. Whatever the metal used, it is important that it should be as clean as possible, and great care is taken to attain this end. The electrode is usually in the form of a cylinder closed at one end, the dimensions of which depend on the particular kind of tube for which it is intended, and the closed end is spot welded on to the leading-in wires of suitable pinches. It will be appreciated from what has been said in Section 6 on the cathode fall of potential, that it is desirable to keep the electrode current density near to its "normal" value, in order to make the potential drop at the electrode as small as possible. Thus, the tube current which

should be used will determine the effective area of the electrode. The "effective area" might be regarded as the area covered by the negative glow when the electrode is in operation. In practice, it is convenient and desirable to have the diameter of the electrode very little smaller than the internal diameter of the glass tubing. This ensures that there will be no cathode glow on the outside of the electrode, even when the current density is slightly above "normal." This considerably lessens the sputtering of the electrode material on to the glass walls.

After fitting the electrodes, the tube is sealed on to the pumping system and evacuated. Before finally filling with the rare gas, it is subjected to repeated heavy discharges, which serve to remove impurities from the walls and electrodes. Finally the tube is filled with pure neon to a pressure of a

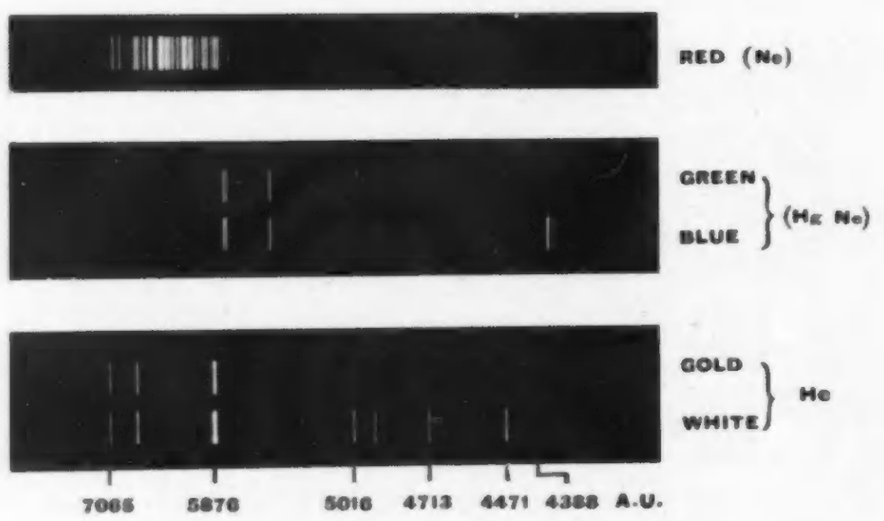



**Fig. 25.—Spectrum photographs of various coloured tubes.**

few mm. and sealed off. Blue tubes are treated in a manner similar to that described above, but a little mercury is introduced in addition to the rare gas. Finally the tubes are aged for a considerable time.

After ageing, the tubes are mounted and tested out with their individual transformers. In order to decide the number of transformers which will be required for a given sign, it is necessary to know the volts drop per foot length of tube, and the cathode fall of potential. The actual values of these characteristics vary with the diameter of the tube, the size and nature of the electrodes, the pressure of the gas filling, etc., and also to some extent on the method of manufacture of the tubes. The maximum transformer voltage is fixed by local authorities, and does not usually exceed 5,000 volts. Transformers of various types are employed, the current through the tubes being regulated by means of high or low tension choke coils or by means of a resistance placed in the secondary circuit. Where the reactance or "stray field" type of transformer is used, no additional current regulation is necessary. This advantageous method has been patented,* and is the one employed by Messrs. Claude-General Neon Lights, Ltd. Another system which is sometimes adopted consists in using a single large transformer, from which a number of sections are run in parallel, adjustable choke coils being distributed to regulate the current in each section.

The range of colours obtainable from positive column discharge tubes by the use of coloured glass tubing is limited, owing to the discontinuous nature of the spectra emitted. The red colour of neon and the blue of mercury represent the aggregate effect on the eye of all the lines in the visible spectra emitted from these tubes. The familiar green colour is obtained by filtering out the strong blue line in the mercury spectrum by means of a yellow glass, the resultant green colour being made up of the remaining strong green and yellow lines. The colour is enhanced by using a uranium glass, which gives a green fluorescence under the action of the powerful ultra-violet radiation of the mercury discharge. This conversion of ultra-violet radiation into visible light results in a considerable increase in luminous efficiency over that obtained with non-fluorescing yellow glass. With neon, however, no additional colours can be obtained by the use of coloured glasses, since the red colour of neon is made up chiefly of lines from one region of the spectrum. With helium the case is different, and it is possible to obtain a useful range of colours with this gas by using suitable coloured glass tubing. Thus, for example, a rich yellow light is obtained by using a glass similar to that employed with mercury for green tubes. Fig. 25 shows spectrum photographs of red, blue, green, white and yellow tubes. The absence of neon lines from the blue tube (neon-mercury) should be noted.

Efforts to obtain useful new colours by utilizing mixtures of the rare gases have not met with much success owing to the tendency of one component of the mixture to predominate, even where the partial pressure of this component constitutes only 1 to 10 per cent. of the total pressure. A tube which, for example, contains neon and mercury emits only mercury radiation, while a tube containing about 10 per cent. of neon in helium can scarcely be distinguished from a pure neon tube. The explanation of this phenomenon lies in the different magnitudes of the resonance potentials, which for helium, neon and mercury are 19.4, 16.6 and 4.9 volts respectively. It can be shown that the probability of an electron acquiring energy much greater than the lowest excitation potential of the gas mixture is very small, hence the component of the mixture with the high resonance potential is scarcely excited, unless its resonance potential does not differ much from that of the other component. With helium and neon, where the resonance potential of the former exceeds that of the latter by only a few volts, the helium concentration must be greater than about

* Patent No. 210053.

90 per cent. to make any change in the colour of the neon. Another difficulty, which has now been overcome by the use of a special type of electrode, arose due to the selective "clean-up" which occurs in discharge tubes when two or more gases are present. This is particularly noticeable in the case of a small percentage of neon in helium, where the heavy neon atoms rapidly clean up under the influence of the high cathode fall characteristic of helium.

The life of the finished tubes depends on a number of considerations, among which might be mentioned the mode of manufacture and the nature and pressure of the gasfilling. It has been shown at the G.E.C. Wembley Research Laboratories that the life of a positive column discharge tube, such as is used for sign work, is given approximately by the expression –

$$L = \frac{k\,p^n\,l\,d^2}{I^2}$$

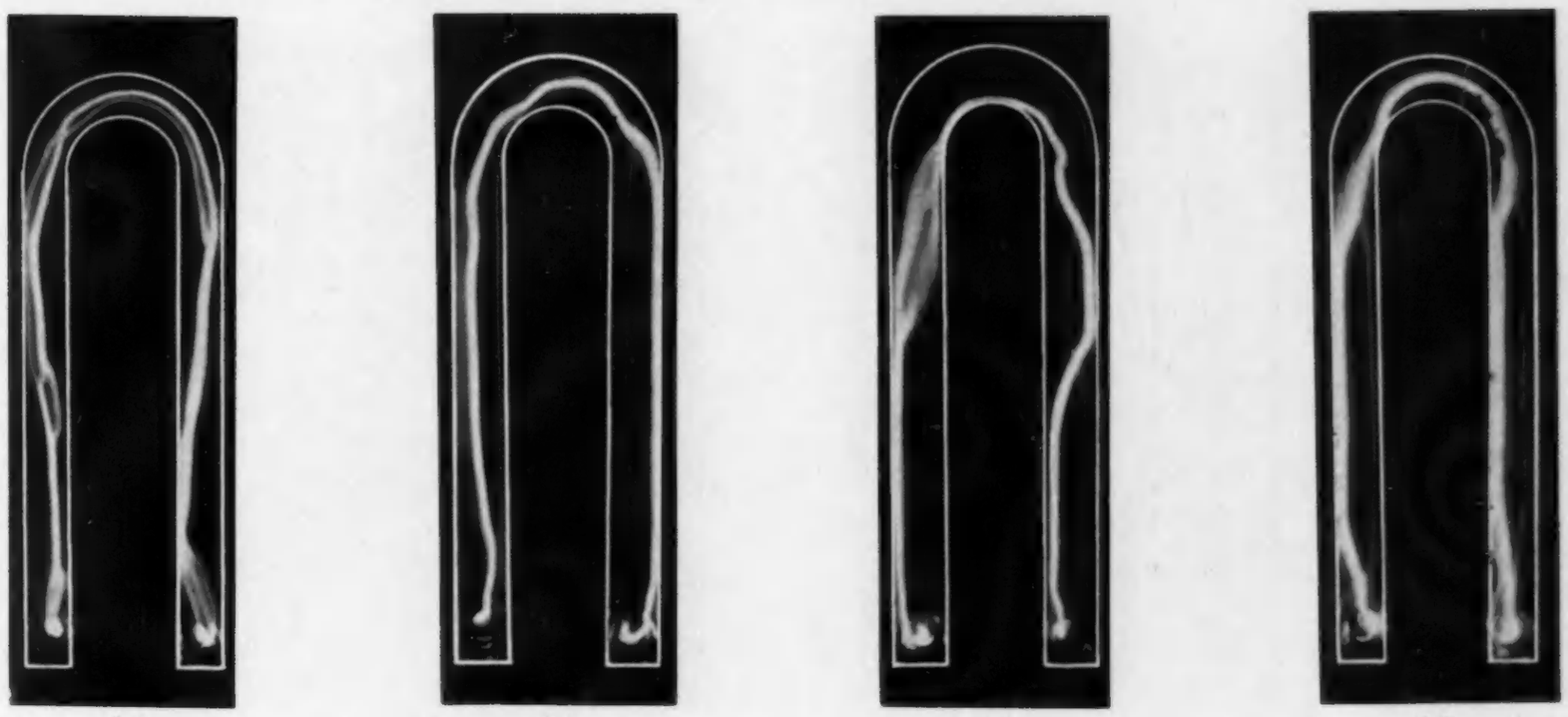
where $L$ is the life of the tube in hours.
$p$ is the pressure of the gas.
$l$ and $d$ are the length and diameter of the tube.
$I$ is the current through the tube.
$n$ is a constant greater than unity.
$k$ is a constant depending on the method of manufacture of the tube.

From this expression it will be seen that increasing the pressure of the gasfilling may considerably increase the life. Increasing the pressure above a certain value, however, seriously impairs the luminous efficiency of the tube, and a pressure of about 10 millimetres of mercury is rarely exceeded. The optimum luminous efficiency occurs with neon at a pressure of 1 or 2 millimetres of mercury.

Apart from accidental breakages, the usual cause of failure of a tube is the disappearance or clean up of the gasfilling. This clean up of rare gases in discharge tubes has been the subject of considerable study, and no complete explanation of it has been forthcoming. There is little doubt, however, that most of the gas disappears on to the freshly sputtered film of electrode material. It is for this reason that it is important to minimise the sputtering, or cathodic disintegration, as it is called.

### (19)—"RIPPLE NEON" AND OTHER SPECIAL EFFECTS.

Mention has already been made in Part I. of this article of a new form of positive column discharge, developed at the Wembley Research Laboratories of The General Electric Company, Limited, for application to "Neon" sign work. In this, the positive column is caused to assume the

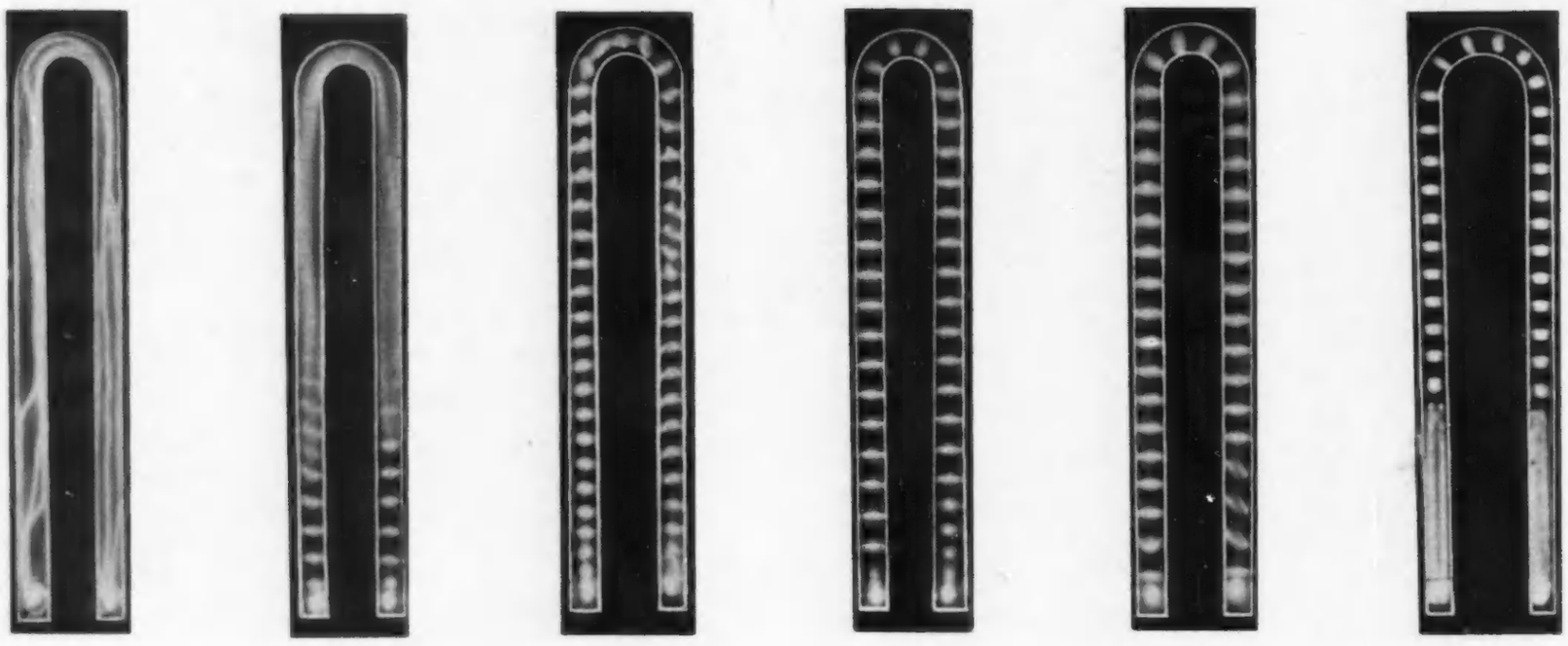


(a) (b) (c) (d)

**Fig. 26.—Reproduction from actual photographs of various forms of blue ripple discharge. The tube outlines have been drawn in.**

form of one or more narrow cords of light, each about one-fifth the diameter of the tube. The movement of these cords inside the tube has given rise to the name "Ripple Neon," by which this animated positive column form of discharge is known commercially. When only one cord of light is present the movement is comparatively slow and usually of a sinuous nature. Sometimes, however, the constricted column is perfectly straight, and rotates around the axis of the tube. When several cords are present, their combined movement gives the appearance of a rapid ripple. This movement of the positive column depends on the action of a trace of certain organic substances causing the discharge to become constricted. One may suppose that owing to the breaking up of the molecules of the impurity by the discharge, the concentration of impurity and therefore the electrical conductivity, varies across any section of the tube. The discharge takes the path of highest conductivity, and this path is changing its position and shape continuously owing to the removal of decomposition products of

the vapour by the clean up effect of the discharge. At the same time fresh vapour is constantly entering from a special side tube. It seems probable that electrostatic charges on the walls of the tube also play a considerable part in keeping the constricted column in motion. Fig. 26 (a), (b), (c) and (d) are actual photographs of various forms of the blue ripple discharge. The same effect is at present being developed in neon, and many beautiful effects have been obtained in the Laboratories with this gas. Actual photographs of some of these effects are shown in figs. 27 (a), (b), (c), (d), (e) and (f), which represent a sequence of discharge forms which occur as the current through the tube is decreased and then increased again. Fig. 27 (a) shows the neon ripple. This is very similar to the blue ripple already described, except that it consists of several constricted cords : (b), (c) and (d) show stages in the development of the striated discharge : (e) and (f) show the breaking up of the striations and the re-formation of the ripple discharge.



(a) (b) (c) (d) (e) (f)

**Fig. 27.—Reproductions from actual photographs of various forms of neon ripple and striated discharge. Here again the tube outlines have been drawn in.**

### (20)—DISCHARGE TUBES WITH EXTERNAL ELECTRODES.

Discharge tubes fitted with external electrodes are sometimes used as indicators on high tension plant. Tubes of this type have been employed on high tension power transmission lines, and may come into more widespread use for this purpose. They are made in various lengths from about 1 to 4 feet, and are simply hung on to one of the lines, or in the case of voltages between about 5,000 and 15,000 they are suspended between two lines or between one of the lines and earth. In either case the glow is brought about by the passage of a very small capacity current through the gas, due to the high potential established between the ends of the tube. The use of small tubes of the external electrode type for testing sparking plugs is well known.

### (21)—THE HIGH FREQUENCY ELECTRODELESS DISCHARGE.

Up to the present the mechanism of the discharge maintained in tubes between metallic electrodes has been discussed. There is, however, another type of discharge which is coming increasingly into prominence, and although it has not yet had much technical application, it seems worth while to mention it here rather briefly. This is the discharge excited by high tension, high frequency oscillations.

If an electrodeless tube filled with, say, neon to a pressure of a millimetre or so of mercury, is placed in a high tension high frequency alternating field, a discharge will be maintained if the rate of formation of ions is just more than sufficient to compensate for their disappearance by recombination, and, especially in small diameter tubing, by diffusion to the walls. There is now no loss of ions caused by neutralization at the electrodes, and therefore no ionization is necessary other than that due to collisions between gas molecules and electrons vibrating under the high frequency field. Perhaps the simplest way to generate the high tension high frequency oscillation is by means of the well known Tesla apparatus, the action of which will be understood by reference to fig. 36. *Tr* is a transformer or induction coil capable of giving a secondary voltage of several thousand volts. The condenser *C* is charged up to the break down voltage of the spark gap *S*, when a spark passes. An oscillatory current flows in the coil *L*, the frequency of which is inversely proportional to the square root of the product of the inductance *L* and the capacity *C*. Since *L* consists of a few turns of heavy copper wire and *C* is of the order of 0.001 mfd., the product *LC* is very small, and frequencies of the order of $10^5$ per second are readily obtained in this way. If the coil *L* is the primary of a high frequency step-up

transformer, a suitable high tension output may be obtained. A tube filled with neon to a suitable pressure will glow brightly if held near this coil when the high frequency current is passing. A Tesla apparatus such as this has many laboratory uses, as, for example, the examination of the gas-filling of lamps, or of valves which have become "soft."

An electrodeless discharge of a rather different type has recently been applied to television (see Section 13). The tube, which is made of fused silica with a flat transparent window at one end, is about 10 cm. long and 2.5 cm. in diameter. It is filled to a pressure of 2 or 3 millimetres of mercury with neon, helium or neon-mercury according to the colour desired, and excited by placing inside a coil through which a high frequency alternating current is passing. In this case the discharge is maintained by the alternating magnetic field, which may also be assisted by the alternating electrostatic field in the manner of the Tesla excitation mentioned above. Where the permissible voltage in the coil is small (of the order of a few hundred volts) a coil of only a few turns carrying currents of some hundreds of amperes may be used. Considerable energy may safely be dissipated in the silica tube without any fear of melting it, and a very intense discharge can be obtained in this way. Except for special purposes, this method of exciting discharge tubes is not likely to be much used, on account of the poor efficiency and the high cost of the apparatus.

### (22)—THE USE OF DISCHARGE TUBES FOR GENERAL LIGHTING PURPOSES.

If energy were transformed completely into light of maximum visibility, that is of wavelength about 5,500 A.U., an efficiency of some 670 lumens per watt would be obtained. The light would be monochromatic, greenish-yellow in hue, and unsuitable for general illumination purposes. An ideal source which transformed energy into heterochromatic radiation corresponding to the visible portion of the sun's radiation, would have an efficiency of some 200 lumens per watt. No such complete transformation of energy into visible radiation has ever been achieved practically, for most light sources radiate much of their energy as heat, and frequently some in the ultra-violet region of the spectrum as well.

The radiation from a heated body shows a maximum value at some particular wavelength, and falls away continuously on either side of this. The wavelength at which the maximum of radiation occurs decreases as the temperature of the body increases. The sensitivity of the eye to radiation shows a similar maximum at about 5,500 A.U., and falls away to practically zero in the red at about 7,500 A.U. and in the violet at about 4,000 A.U. A maximum luminous efficiency, of some 93 lumens per watt, will be realized with a radiating heated solid if the maximum of its radiation occurs at about 5,500 A.U., but the temperature required is impracticably high, some 6,500°K. The working range for tungsten is between about 2,400° and 2,800°K., depending on the type of lamp made, and the corresponding luminous efficiencies are some 10–18 lumens per watt. It is unlikely that much improvement upon these values can be expected with incandescent solid radiators. Even at the melting point of tungsten, 3,600°K., the efficiency is only some 50 lumens per watt.

Gaseous discharge tubes were early recognized as possible units for general lighting purposes, but the high voltage required in all but the smallest units, together with the relatively low luminous efficiencies obtained, made them unattractive compared with the rapidly developing metal filament lamp. Recent developments serve to bring the possibility of an extension of discharge tube lighting into prominence again, since these disadvantages have in great measure now been removed in the hot cathode lamp.

Early development of this type of lamp is due to Forney and Found in America and Pirani in Germany, although the hot cathode discharge has been the subject of academic researches for many years.

### (23)—HOT CATHODE LAMPS.

The advance has been brought about by replacing the cold metal electrodes of the high voltage tubes by hot, thermionically emitting cathodes, usually employing oxides of the alkaline earth metals as the active material. The wasteful cathode fall of potential is thereby reduced from about 180 volts to 20 volts or less, and comparatively long tubes may be operated on voltages of 200–240 volts without intermediate high voltage transforming gear. High current densities up to several amperes per square cm. of cross section of tube become possible, so that compact units of high luminous output are practicable. Tubes filled with neon at a few millimetres pressure, or with neon and mercury, in various sorts of glasses, radiate orange, blue and green radiation with an efficiency considerably in excess of that afforded by tungsten filament lamps and coloured filters. Tubes containing a rare gas filling, usually argon, together with metallic sodium or cadmium, yield radiation characteristic of the vapour of the metal. Thus a sodium vapour lamp gives an intense yellow light, due almost entirely to the familiar D-lines at 5,890 and 5,895·9 A.U., the luminous efficiency amounting to some 30 to 50 lumens per watt according to the size of the tube. This lamp has been made possible by the development of a special glass, characterised by a high boric acid content, and resistant to sodium

vapour at high temperatures. Sodium vapour lamps had previously been impracticable since all ordinary glasses, and quartz, blacken rapidly in the sodium vapour discharge. Comparable efficiencies are obtainable with cadmium tubes, which give a blue light, and for which a similar vapour-resistant glass is required. The principle is being extended to other metallic vapours, such as lithium and magnesium. The mercury vapour lamp has been

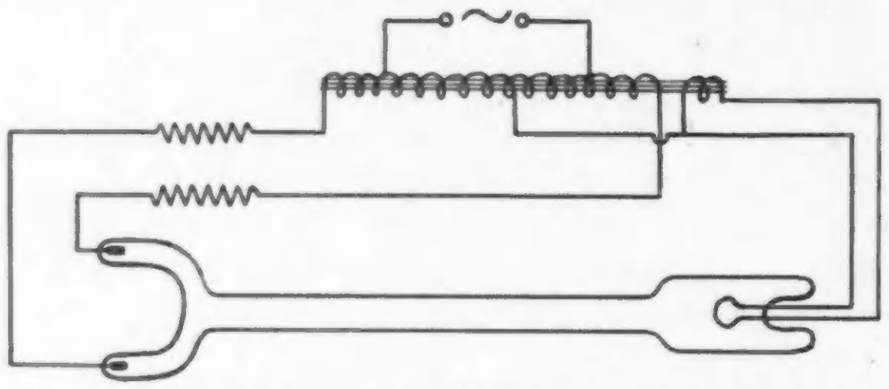


**Fig. 28.—Hot cathode lamp circuit for single phase A.C. supplies.**

modified and improved, and a new type with oxide cathodes and a rare gas subsidiary filling, has twice the luminous efficiency of a gasfilled lamp of the same rating. At the same time the absence of red radiation, characteristic of the early mercury vapour lamps, has to a certain extent been overcome by operating the discharge at a very high pressure of mercury vapour, when some red radiation is excited.

There are many possible applications for hot cathode lamps of these various types. The neon tube unit, on account of its efficiency, compactness and high mist and fog penetrating powers, makes a convenient beacon light. The efficiency is greater than in the high voltage type of tube, and the absence of dangerous potentials is advantageous, especially to aircraft. Alone, or in combination with metal filament lamps, the neon and various other coloured tubes may be usefully employed for decorative lighting. Their high efficiency, and a shape convenient for use in trough reflectors, make them very

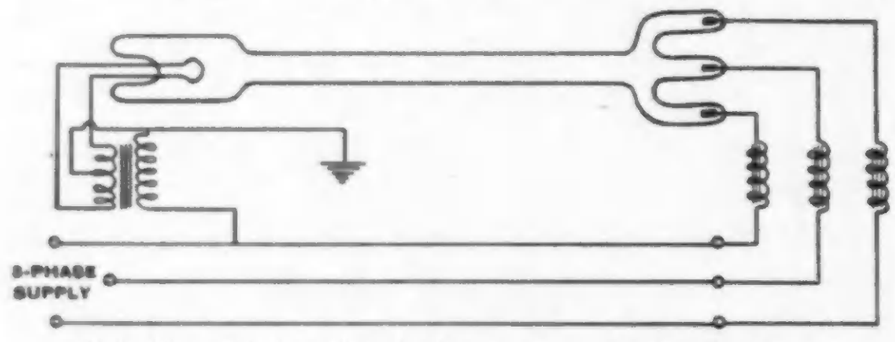



**Fig. 29.—Hot cathode lamp circuit for 3-phase supplies.**

suitable for colour floodlighting. Simple control for "dimming" can be arranged. Fittings combining blue mercury or cadmium tubes with tungsten filament lamps may be adjusted to produce a satisfactory approximation to daylight. The discharge tube provides green and blue radiation in which the filament lamp is deficient compared with daylight, and the overall efficiency of the combination is high. The mercury vapour discharge continues to be a valuable source of ultra-violet radiation in its new form and with a special glass of suitable transparency. Sodium and cadmium vapour tubes are useful as radiation standards, and for use with various laboratory instruments.

For purposes of general illumination the same difficulties in producing an efficient white light with a mixture of gases or vapours are encountered as were outlined in Section 18. As yet no single low voltage tube has been developed which gives a perfect white light with a high efficiency. However, a combination of a neon and a special mercury tube in a suitable fitting gives a pleasing white mixed light, and has a luminous efficiency higher than that of a tungsten lamp of similar rating.

When the cathode in a discharge tube is designed to act as an efficient thermionic emitter, capable of yielding an electron current comparable with the discharge current required, positive ion bombardment of the cathode is no longer necessary to produce electron emission. Positive ions from the discharge, however, serve to neutralize the negative space charge around the electrode. The cathode fall of potential need be no greater than that required

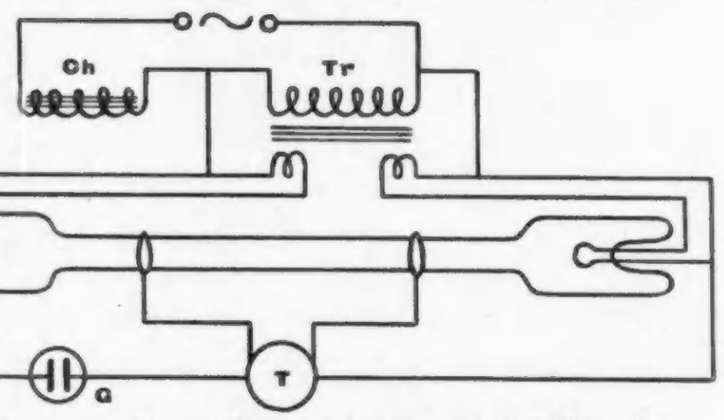



**Fig. 30.—An alternative arrangement to Fig. 28.**

to produce ionization in the gas, and therefore never exceeds 25 volts (see Table I). These conditions at the cathode are characteristic of an arc discharge, with a negative or practically zero slope to the volt-ampere characteristic.

On D.C. circuits the tube is furnished with a hot cathode and a suitable anode, and is operated with a series resistance, which may itself be the heating unit of the cathode. On single phase A.C. supplies a second anode may be added and the circuit of fig. 28 used. For a three-phase supply, the principle may be extended to the circuit of fig. 29. Alternatively, for single phase circuits, the arrangement of fig. 30 may be adopted, hot cathodes being placed at either end of the tube, each acting alternately as cathode and anode during succeeding half cycles. A transformer *Tr* supplies heating current to the cathodes, and a choke *Ch* stabilizes the discharge. Owing to the wide separation of the electrodes and their comparatively close proximity to the tube walls, the initial striking potential of the tubes is frequently 1,000 volts or more, although

once alight, the discharge will be maintained at normal supply voltages of 200–240 volts. Various starting devices may be adopted. A momentary surge of several thousands of volts may be given by alight by the use of a small series negative glow lamp *G*. Initially the full mains voltage is applied to *G* and *T* in series, but when the arc strikes a voltage drop is set up across the choke, and *G* will

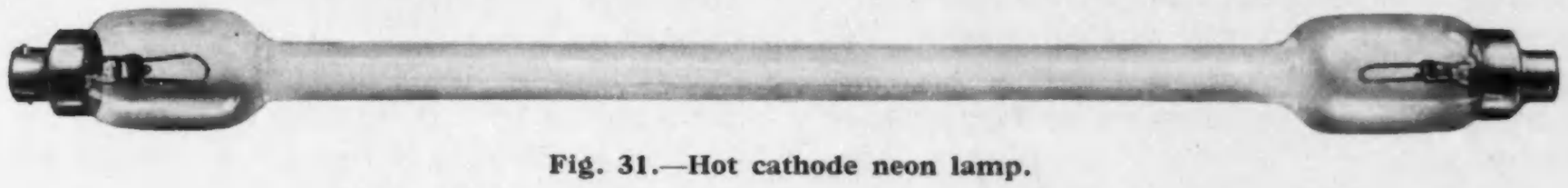


**Fig. 31.—Hot cathode neon lamp.**

**Fig. 32.—Hot cathode sodium lamp.**

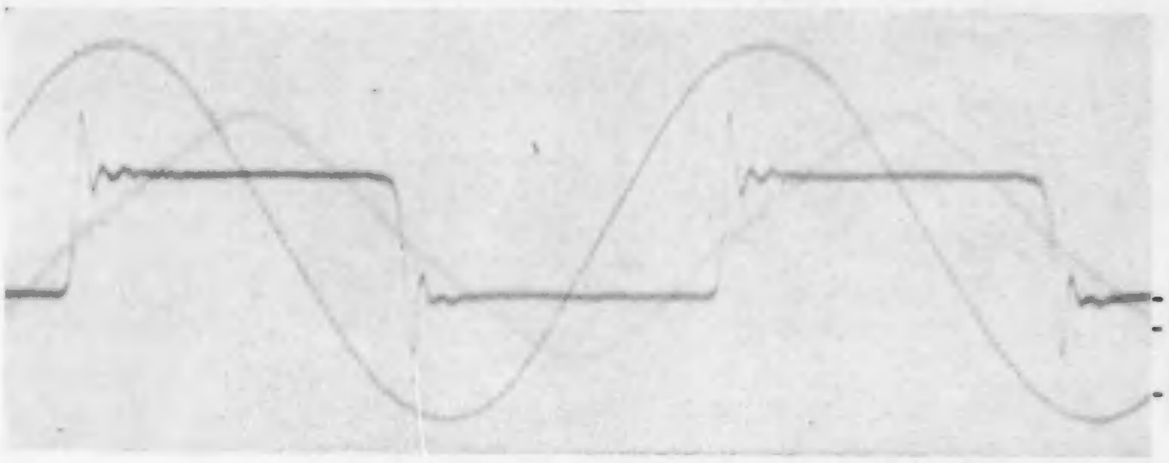
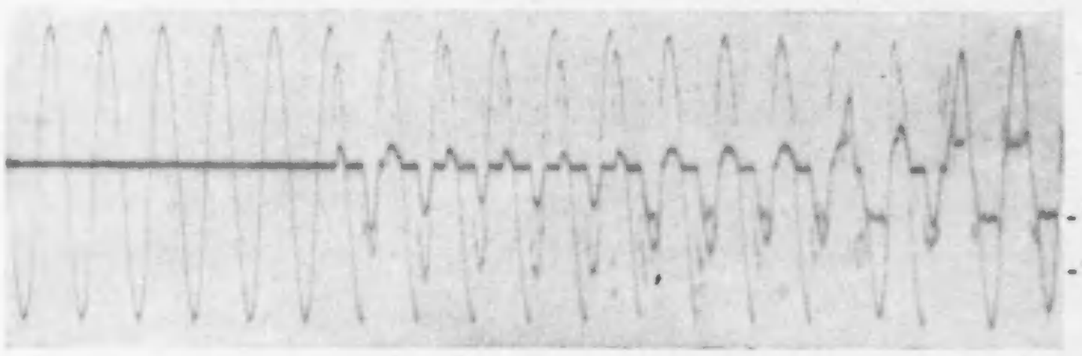



**Fig. 33.—Oscillogram showing the relation between supply voltage, discharge current and potential across the tube when operating in the circuit of fig. 29.**



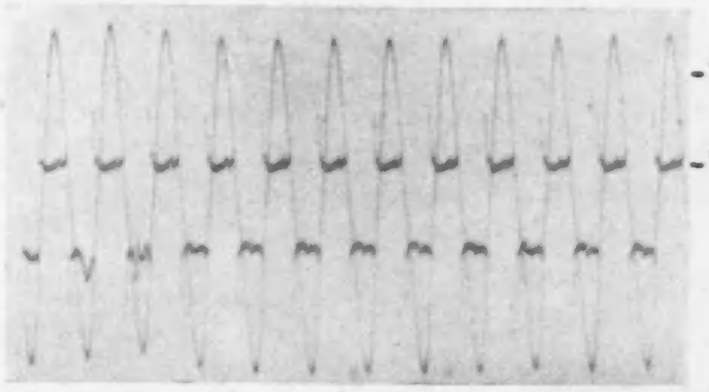




**Fig. 34.—Oscillogram showing incipient arcs at each cathode during an early stage of the striking of the discharge.**

sharply breaking a subsidiary circuit. Other methods include the use of auxiliary electrodes near the cathode, or, as in fig. 30, the provision of a small high frequency or Tesla apparatus, *T*, which initiates ionization within the tube and allows a rapid building up of the arc discharge. The coil is automatically cut out of circuit when the tube is not operate at the reduced potential. At the same time the transformer contributes less heating current to the cathodes, whose temperature is now in part maintained by the discharge current.

Figs. 31 and 32 illustrate the 2 ampere neon and sodium tubes for use in circuits of this nature. Each is some 70 cm. in length, and the sodium tube

is sealed within an evacuated jacket to increase its operating temperature and hence the vapour pressure of sodium. Many modifications of the circuit of fig. 30 are possible, and considerable simplification can be effected. For example, tubes some 50 cm. long may be operated direct from 200–240 volt supplies with a choke or resistance as the only auxiliary gear, the tube being self-striking so soon as the supply is switched on.

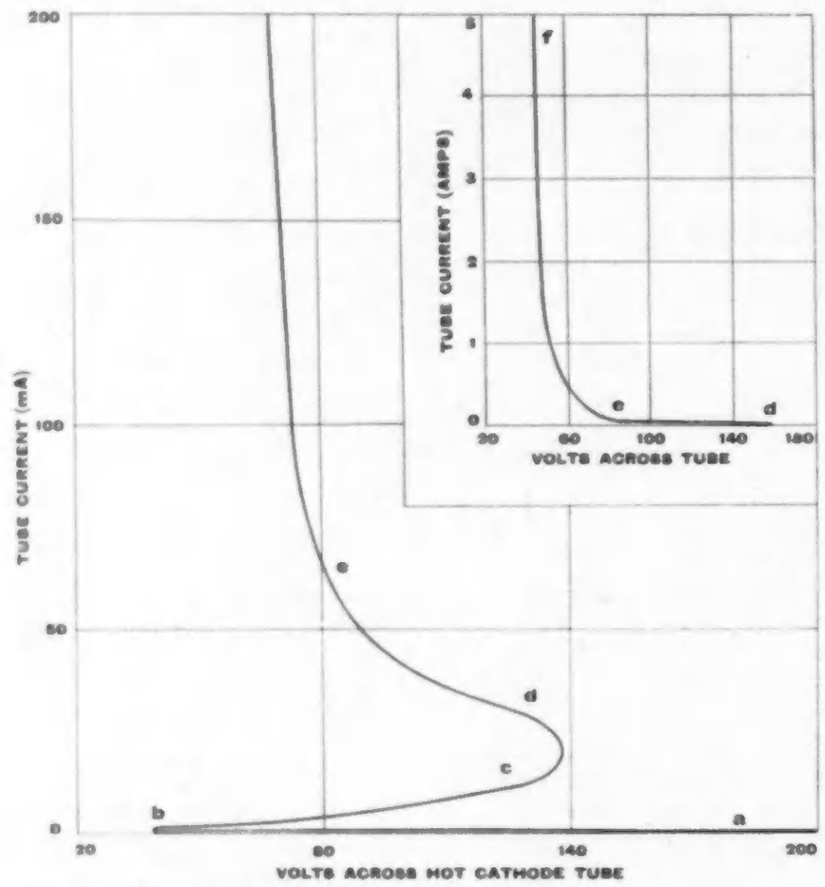



**Fig. 35.—Characteristic of hot cathode tube.**

Fig. 33 reproduces an oscillogram showing the relation between the supply voltage, the discharge current and the potential across the tube, for a tube operating in the circuit of fig. 30. It is clear that the discharge is extinguished each half cycle and re-strikes early in the succeeding half cycle. In the tube itself, current and voltage are in phase, but the stabilizing choke introduces a lag between these and the supply voltage. Fig. 34 reproduces an oscillogram, showing incipient arcs at each cathode during an early stage of the striking of the discharge.

The complete characteristic, for direct currents, of a short hot cathode tube of the type shown in fig. 30 is given in fig. 35, and may be compared with that shown in fig. 5 for the cold cathode tube. (ab) is again the portion traversed with a very high series resistance. Since the cathode is small in area, the region of normal cathode fall (b) is restricted. (bc) represents the region of abnormal cathode fall and at (d) the discharge passes into the arc stage shown by (def).

### (24)—DOMINANT HUE OF NEON.

Mention has already been made of the increasing use of positive column neon tubes for such purposes as aviation beacons and landing line indicators. The distinctive red colour of neon renders it particularly suitable for danger signals on obstructions, such as hangars, high buildings, power transmission towers, etc. It is desirable to have some data relating to the dominant hue of tubes of this description, and the change in this dominant hue with the current density.

The following table gives these data for both cold and hot cathode tubes.

Table 3.

| Type of Tube. | Tube Diam. cm. | Current Density. | Hue Wave Length. A.U. |
|---|---|---|---|
| Cold Cathode | 1.5<br>1.1 | 20 milliamps./cm²<br>26.5 ,, | 6190<br>6170 |
| Hot Cathode | 2.2<br>3.5 | 0.53 amperes/cm²<br>0.62 ,, | 6155<br>6140 |

It is evident from the above that an increase in current density slightly reduces the hue wavelength, due to some slight extra excitation of the yellow and green radiation in the neon spectrum.

### (25)—DISCHARGE TUBE LIGHT AND PLANT GROWTH.

Researches on the effects of artificial light on plant growth have recently led to experiments with discharge tubes for this purpose. In particular neon tubes have been used, and it has been reported that the deep red light from this gas stimulates the formation of the green colouring matter (chlorophyll) and brings about an increase in firmness of the plant due to better assimilation. It is claimed that the

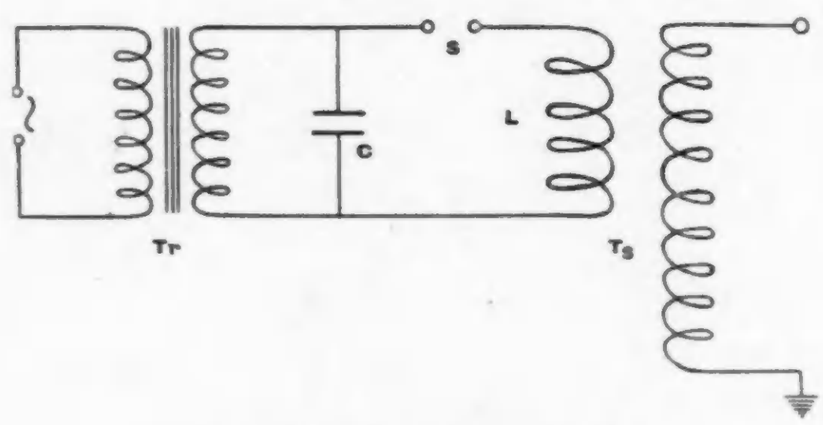



**Fig. 36.—Tesla coil circuit.**

absence of considerable heat radiation prevents the excessive "length growth" which takes place with ordinary incandescent lamps. Considerable increase in the yield from certain fruit plants which have been exposed to neon light has been reported, and, very recently, experiments have been conducted on the growth of tomatoes exposed to the light of a sodium vapour discharge tube.

# The Firing of Lancashire Boilers by Pulverized Fuel.

By H. L. WOOD, B.Sc.

Pulverized Fuel Dept., Fraser & Chalmers Engineering Works
of The General Electric Co., Ltd.

ALTHOUGH the successful application of pulverized fuel firing to cement kilns and water tube boilers has been an accomplished fact for a number of years, it is only comparatively recently that success has been obtained commercially with fire tube boilers, such as the Lancashire. The first attempts to fire these boilers consisted in fitting burners directly in the fire tubes, several patents being taken out and experimental plants developed by pioneers on these lines at the end of the last century. While some of the methods employed gave comparatively successful results for short periods, no commercial installations were entirely successful, the failures being chiefly due to burner, grinding, feeding and ash troubles.

The next attempts more or less followed the lines of standard practice on water tube boiler work. An external combustion chamber was built in front of the boiler and two connecting necks were taken from the chamber to the boiler flues proper. Several installations were completed on this principle, but it was found that not only were the capital and maintenance costs high, but in addition difficulties were encountered in cooling the necks between the combustion chamber and the boiler. Furthermore, the space required in front of the boiler by the combustion chamber and pulverizing plant was such as to preclude the use of this method in a large number of installations.

A great deal of pioneer work in the firing of water tube boilers and metallurgical furnaces had been done at the Fraser & Chalmers Engineering Works, and acting on the belief that the only commercially successful method of firing a Lancashire boiler would be by direct firing without a combustion chamber, three Lancashire boilers at a large malleable iron foundry were equipped in 1926 on this principle, the pulverized coal and air being tapped from a circulating main. The first of these boilers, photographed shortly after the plant was started up, is shown in fig. 1. Refractory linings were used for the burners and these linings were continued for some distance inside the flue, the ash being slagged and tapped from the hole seen in the under side of the burner. These boilers were in regular use for about two to three years until they were displaced by waste heat boilers fitted to the malleable iron melting furnaces. It is believed that this installation was one of the earliest, if not the first, commercially successful application of pulverized fuel firing to Lancashire boilers without the use of any external combustion chamber.

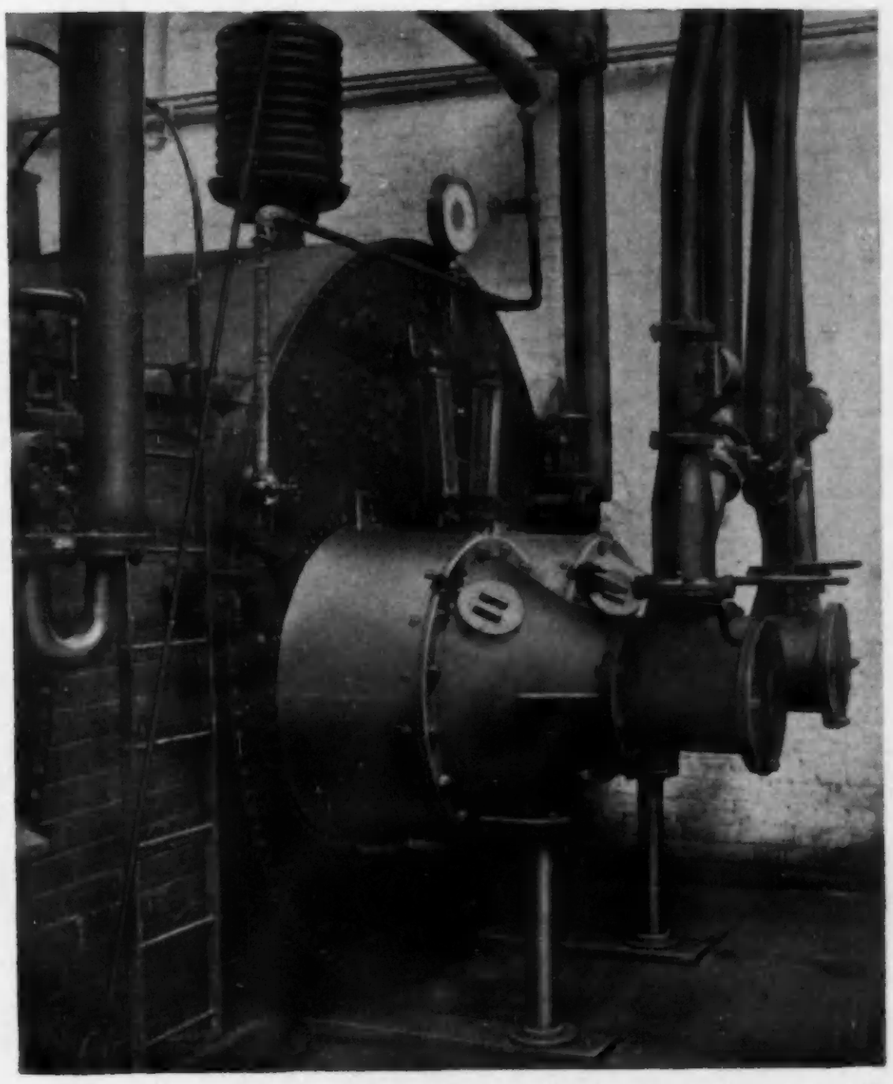


**Fig. 1.—One of three Lancashire boilers equipped with F. & C. pulverized fuel firing system. The installation was completed in 1926 and was the first commercially successful application of pulverized fuel firing to Lancashire boilers without the use of any external combustion chamber.**

Since that date a very considerable amount of development work has been undertaken to improve the efficiency, evaporation and ease of control and to reduce the power consumption and maintenance costs. In the course of these developments refractory linings have been dispensed with, as these materially reduce the effective heating surface of the boiler and require periodical repairs and renewals. While slagging the ash was successful with some coals, difficulties were experienced with others. The elimination of refractories enabled slagging to be abandoned,

and the ash is now handled in a perfectly friable state even at high $CO_2$ percentages.

From these investigations a clear understanding was obtained of the features essential to success. In the first place, with a boiler of the Lancashire type, the cooling effect in the flues is very considerable and if the grinding of the fuel is not uniformly fine a high carbon loss in the ash is inevitable, due to the coarser particles not being completely burnt before they reach a zone in the boiler where the temperature is insufficient to maintain further combustion. How low this loss can be kept is shown in the table of test results given on page 82.

Then again, to obtain good combustion conditions it is essential that the coal and air supply to each flue of the boiler be under accurate and easy control. After a number of experiments, a slow speed grinding mill has been adopted as standard so that the fine product necessary can be obtained and its supply maintained continuously. Further, it was found very difficult, if not impossible, to split up a mixture of coal and air in a pipe with sufficient accuracy to give an equal feed to two or more burners, and for this reason a central system, having one feeder for each flue, has been standardized. How each point is catered for is best understood by

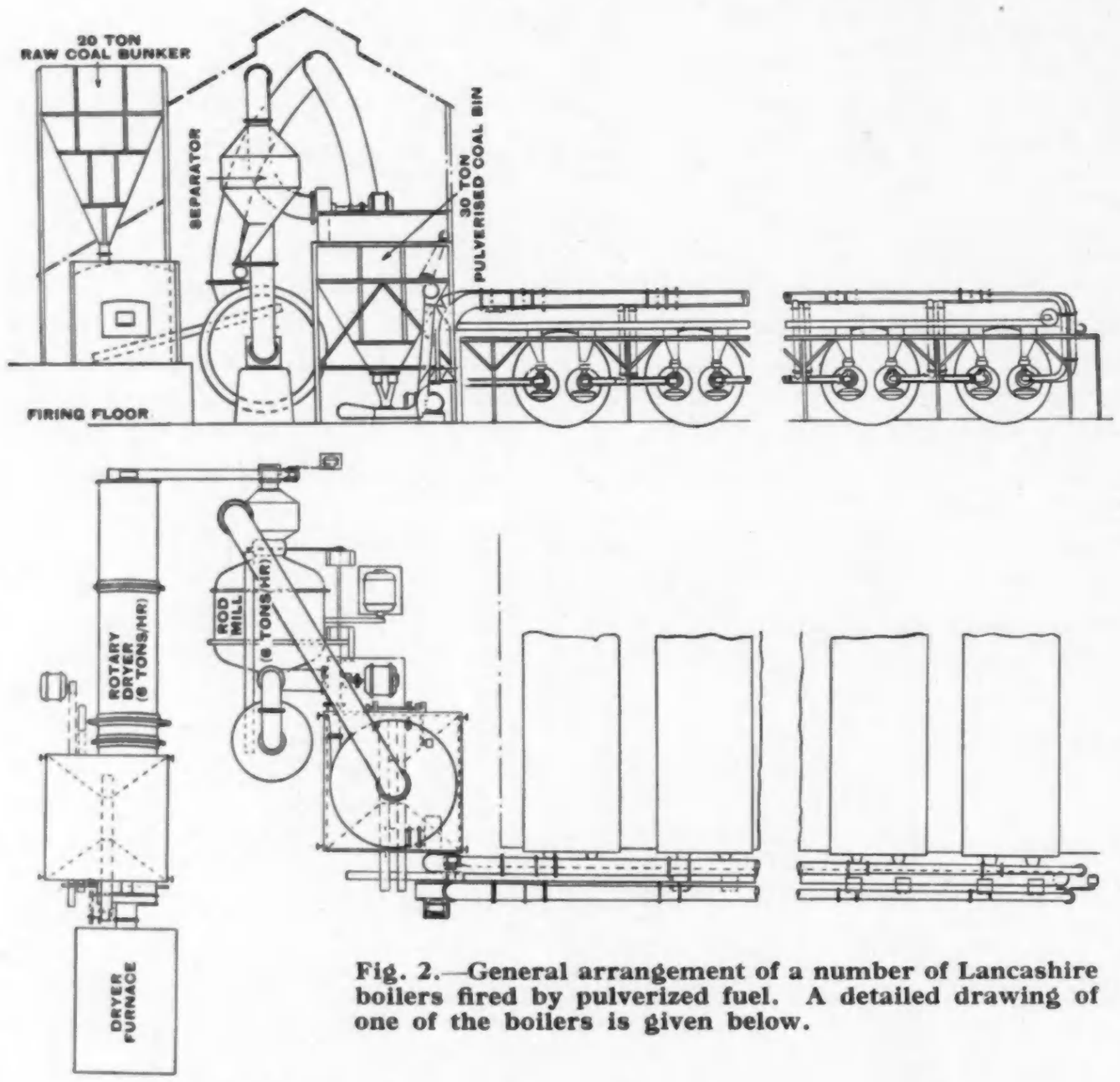
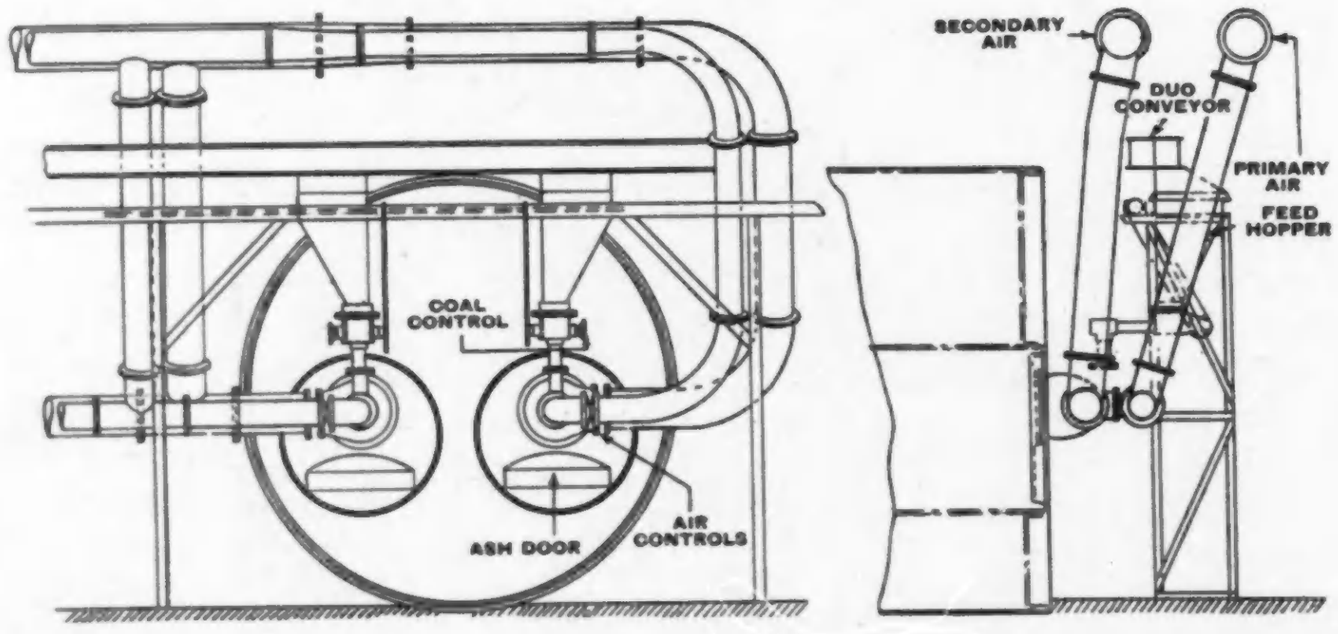



**Fig. 2.—General arrangement of a number of Lancashire boilers fired by pulverized fuel. A detailed drawing of one of the boilers is given below.**



a detailed description of an up-to-date plant such as is shown in fig. 2. The extent of the equipment naturally depends largely on the characteristics and properties of the coal to be used and the size and scope of the plant, but the basic principles are the

Fig. 3.—Internal view of a Rexman balanced rod mill.

same in each case. On a large installation raw coal handling and storage plant would, of course, invariably be required. This equipment would follow normal conveyor practice, and calls for no particular comment in this article.

**DRYER.**

With coals having a moisture content of more than 3 to 4 per cent. a dryer is generally required, the question as to whether a dryer is necessary depending on the tendency of the coal to pack in the storage bin after pulverizing. The choice of dryer is usually governed by the particular conditions of the installation ; a dryer suitable for slack coal or nuts, for example, may be quite unsuitable for drying dust, while the best type of dryer for the latter material may be uneconomical when dealing with larger coal. Generally, a moisture content of 2 per cent. is the most economical figure to which the coal should be dried. This is well below the limit at which packing and feeding difficulties begin, while the increased efficiency obtained by drying below this point is generally not justified by the increased cost involved. Dry coal is also very economical from a grinding point of view, as the output of the mill is increased while the power consumption and maintenance are reduced.

**MILL.**

The essential characteristics of a good mill are uniform fine grinding, low maintenance and power costs and consistent reliability. As previously mentioned, pulverized fuel installations on Lancashire boilers and metallurgical furnaces are particularly exacting in the fineness of the fuel necessary for good results. This rather limits the choice of mill as there are many which are perfectly suitable for water tube boiler work where a coarser product will produce good results, but which will not give the necessary fineness continuously, except at the expense of high power consumption and maintenance costs. A mill pre-eminently suited to this class of work is the Rexman balanced rod mill, the interior construction of which, with the end plate removed, is shown in fig. 3, and a view of a finished mill in fig. 4. The grinding is effected between rods carried in two spiders, one at each end of the mill. These spiders have a number of compartments, each containing an equal number of rods. The mill shell, however, is a common chamber and the spider divisions are distinct only in so far as the rod load is concerned. As the centre of gravity of the rods almost coincides with the axis of rotation of the mill, dynamic balance is practically obtained,

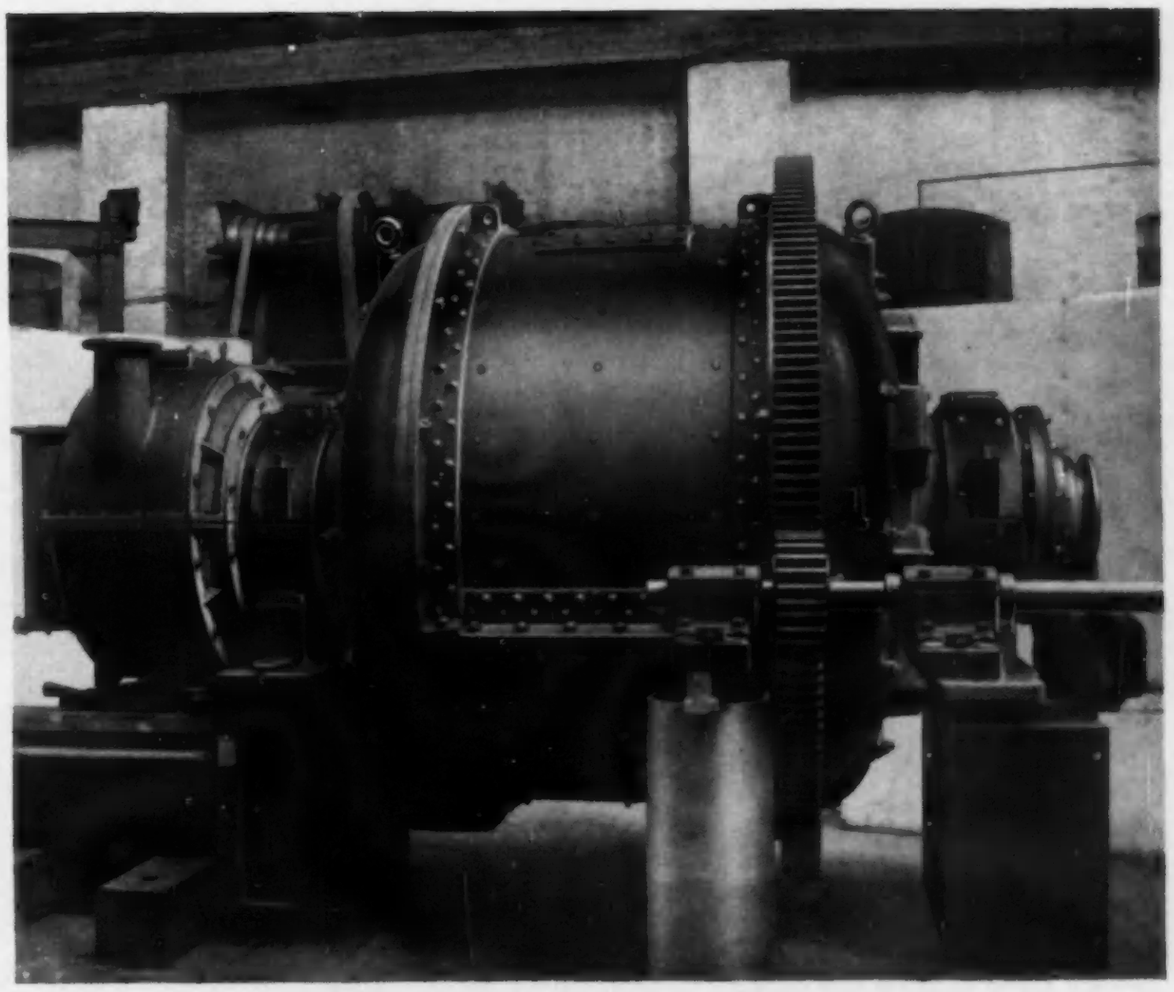


Fig. 4.—Exterior view of a Rexman balanced rod mill.

and, apart from bearing friction and normal mechanical losses in the drive, power is only expended on the actual grinding and circulation of the material. The coal is fed into the mill at one

end and is passed by a delivery tube fitted with a spiral liner to the centre of the mill and delivered to the various divisions of grinding media. The powdered coal is removed by air sweeping equipment working in conjunction with a separator, which is provided with the adjustments necessary to regulate the size of the finished product that is passed to the pulverized coal bin, the oversize being returned to the mill for further grinding.

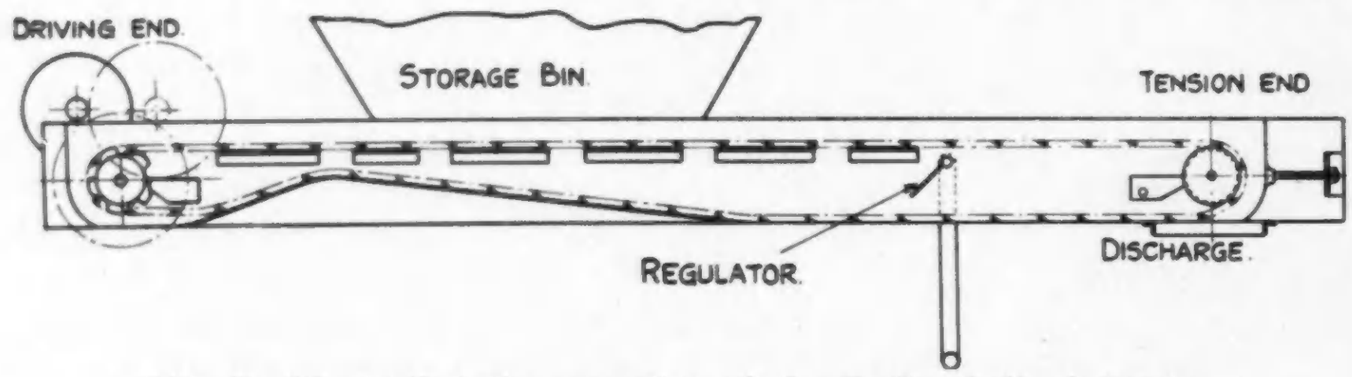



**Fig. 5.—Illustrating the operation of the Redler bulk abstractor.**

One great advantage of this type of mill is that on account of the balance and the small quantity of coal in the mill at any one time, the cost of fine grinding from a power consumption and maintenance point of view is very low, a feature which renders it very suitable for this class of work.

### PULVERIZED COAL BIN AND BULK ABSTRACTORS.

The size of the pulverized coal bin is proportioned to give the storage necessary to bridge over the periods when the mill is not running. The coal is taken from the bin by one or more Redler bulk abstractors, the arrangement of which is shown in fig. 5. The top run of the chain moves the coal along the bottom of the bin until it falls through one of the openings on to the returning chain underneath. The path of this returning chain, as can be seen from the illustration, is so proportioned that, as far as possible, equal quantities of coal are taken from each opening, thus keeping the bin well trimmed. Regulation of the amount of coal removed is effected by the regulating lever which moves an adjustable weir plate as shown in the diagram.

A valuable feature of this feeder is its flexibility, for if the distributing conveyors are unable to take all the coal for which the regulator is set, the chain will pull through the superfluous load. With a positive feeder, such as a screw, difficulty would undoubtedly be experienced in keeping the supply of coal exactly in step with all the various boiler feeders which are fed from the distributing system.

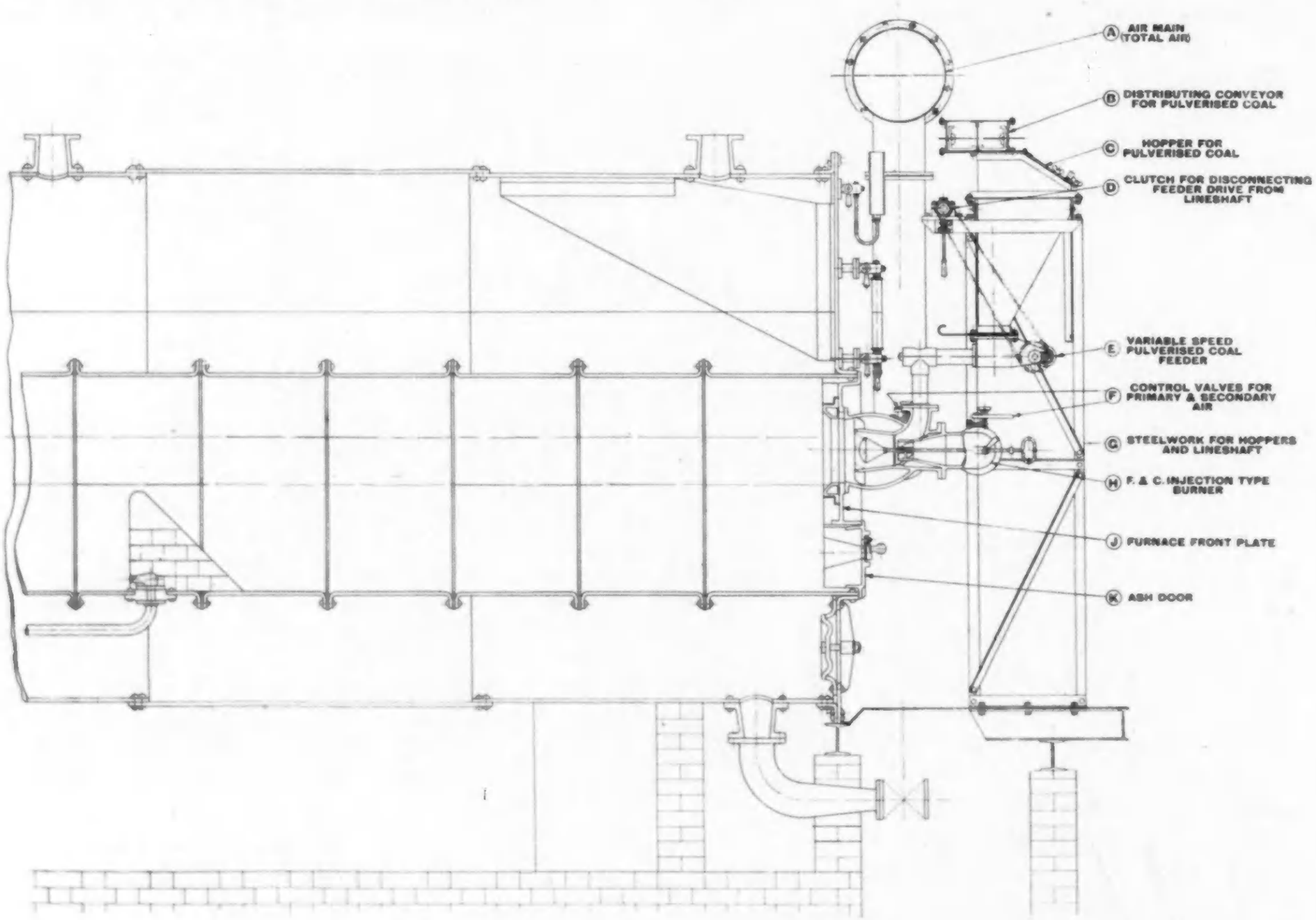

A AIR MAIN (TOTAL AIR)
B DISTRIBUTING CONVEYOR FOR PULVERISED COAL
C HOPPER FOR PULVERISED COAL
D CLUTCH FOR DISCONNECTING FEEDER DRIVE FROM LINESHAFT
E VARIABLE SPEED PULVERISED COAL FEEDER
F CONTROL VALVES FOR PRIMARY & SECONDARY AIR
G STEELWORK FOR HOPPERS AND LINESHAFT
H F. & C. INJECTION TYPE BURNER
J FURNACE FRONT PLATE
K ASH DOOR

**Fig. 6.—The fuel is distributed to the boilers by a special double mechanical conveyor. This and the solid injection burner with its control gear can be seen on the right.**

### DISTRIBUTING PLANT.

The coal is distributed to the boilers by a special double mechanical conveyor which keeps the small hopper over each burner full, the arrangement of the conveyor being shown in fig. 6. This conveyor consists of two troughs, the coal being delivered in one trough and the surplus returning in the other. At the end of the run the coal is transferred from one side to the other by the removal of the division plate between the two sides and the insertion of a plough. The conveying chain consists of a series of L-shaped links attached at equal pitch to a wire rope which runs round a sprocket at each end, the drive being located at one sprocket and the tensioning gear at the other end. These conveyors run very slowly, use little power and are totally enclosed.

### FEEDERS AND SOLID INJECTION BURNERS.

The pulverized coal is fed out of the small hopper over each flue and delivered to the solid injection burner by a screw feeder fitted with an adjustment which is variable over the range of coal requirements of the boiler. This feeder is chain driven from a line shaft running along the front of the boilers, each feeder being fitted with a clutch.

A diagrammatic arrangement of the burner is shown in fig. 7. The primary air enters by pipe A which terminates in an injector D; this causes a suction in the fuel pipe C, down which the coal falls from the screw feeder. Above the screw feeder is an inlet E, through which induced air enters, aerating and helping the coal to mix with the primary air in the burner proper. An adjustable deflector cone F, is fitted in the burner to break up the coal stream and further improve the mixing. The secondary air enters by pipe B, and issues from the burner through the annular space surrounding the coal and primary air chamber. Primary and secondary air supplies are taken from their respective air mains and primary and secondary air control valves are fitted to each burner. The actual

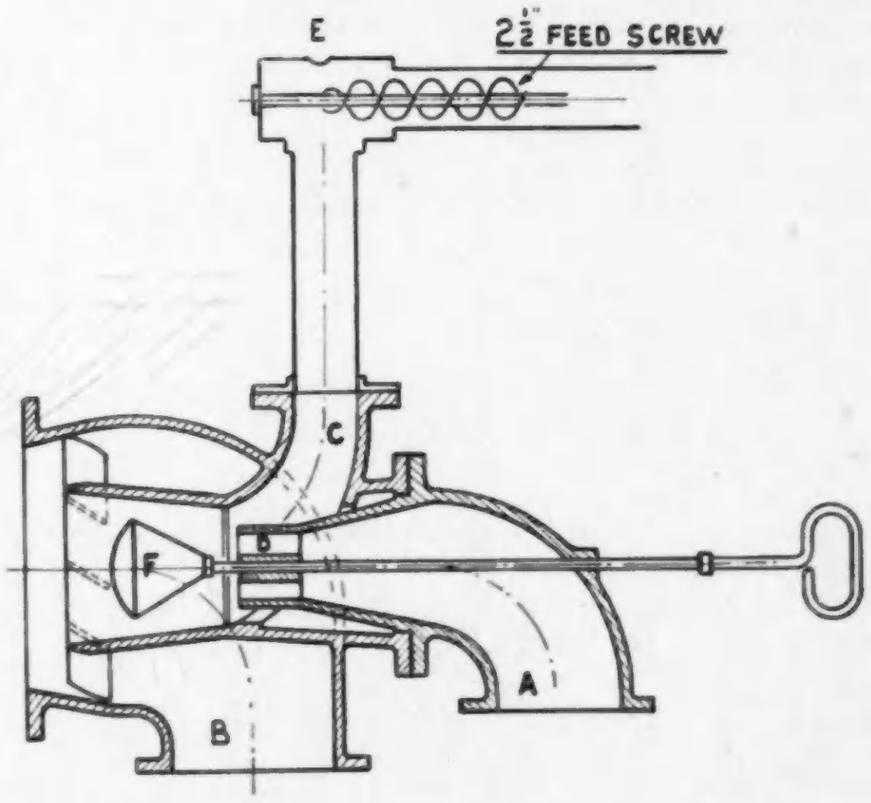



**Fig. 7.—Diagrammatic section of the Fraser & Chalmers solid injection burners.**

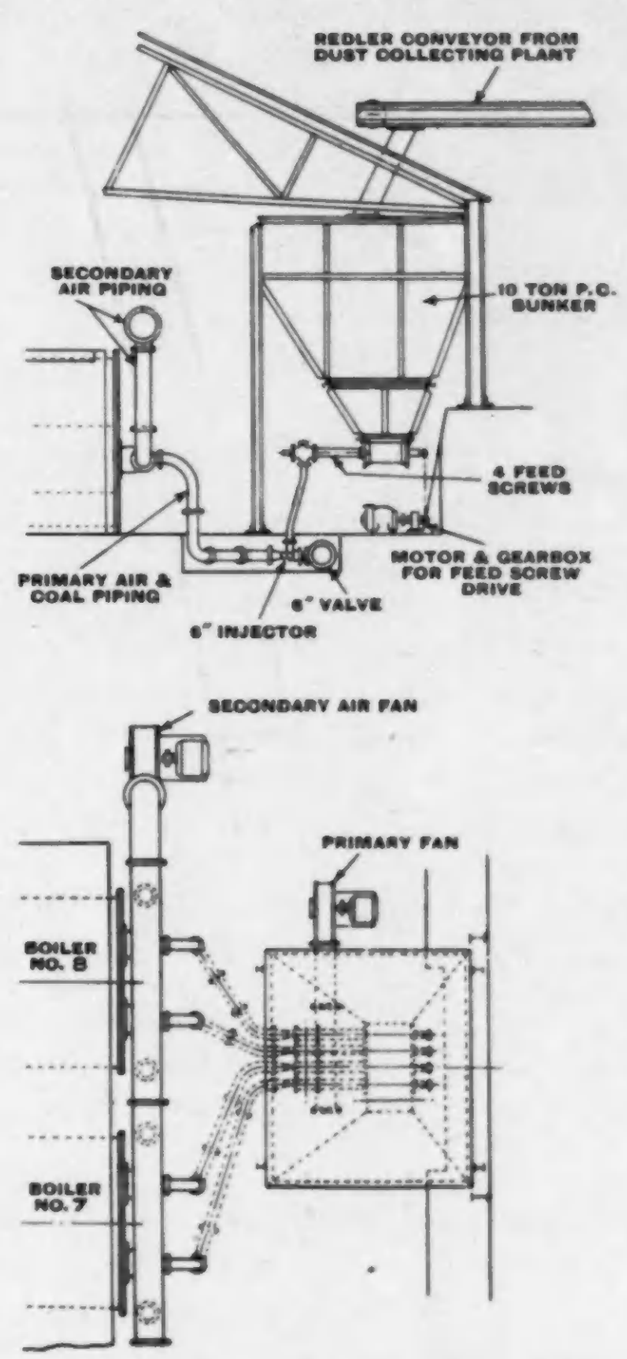



**Fig. 8.—Simplified system of distribution for a small number of boilers.**

arrangement of the burner can clearly be seen in the sectional arrangement shown in fig. 6. It will be seen that the supply of coal and air to each burner can be controlled accurately, and if necessary, each screw feeder calibrated so that the feed to each boiler can be determined within reasonable limits. The latter arrangement overcomes a difficulty often experienced in air circulating systems, as while the amount of coal fed into the main can be measured, it is impossible to tell the amount consumed by any individual boiler.

### ASH DISPOSAL.

For dealing with the ash, soot blowers are fitted in the back of the boiler flues, and in the side and bottom flues. No difficulty is experienced in dealing with the friable ash obtained, as no refractories are used in the fire tubes other than to protect the soot

# TESTS ON 7 ft. 6 in. × 28 ft. 0 in. LANCASHIRE BOILER.

Flues—2 to 3 ft. dia.
Heating Surface—838 sq. ft.
Grate Area—36 sq. ft.

For Pulverized Coal Tests—
Heating Surface—916 sq. ft.

| READINGS RECORDED. | HAND FIRED—FORCED DRAUGHT | | | | | | STOKER FIRED—FORCED DRAUGHT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 | No. 9 | No. 10 | No. 11 | No. 12 By Clients | No. 13 |
| Date | 2-12-30 | 8-7-30 | 9-7-30 | 10-7-30 | 17-7-30 | 15-7-30 | 11-12-30 | 9-12-30 | 23-7-30 | 12-12-30 | 29-7-30 | 20-8-30 | 5-12-30 |
| Duration of test in hours | 8 | 8 | 8 | 8 | 8 | 8 | 7.93 | 7.04 | 8 | 8 | 8 | 8 | 7 |
| Steam W.P. lbs./□" Gauge Sat. | 114 | 131 | 124 | 138 | 136 | 136 | 108 | 118 | 136 | 132 | 128 | 127 | 114 |
| Water Temp. Entg. Boiler | 113°F. | 133°F. | 137°F. | 142°F. | 152°F. | 144°F. | 108°F. | 116°F. | 144°F. | 118°F. | 142°F. | 154°F. | 125°F. |
| Evaporation in lbs. (Total) | 25680 | 32040 | 40176 | 44811 | 47629 | 51179 | 28268 | 31084 | 32670 | 38743 | 44250 | 48300 | 42003 |
| Coal, Total Consumed in lbs. | 6400 | 7200 | 8000 | 8800 | 10800 | 9600 | 6400 | 6550 | 7300 | 8000 | 9725 | 9450 | 9447 |
| C.V. Gross B.T.U's. | 9945 | 10656 | 11146 | 11259 | 9430 | 11083 | 9526 | 9781 | 9600 | 10032 | 9812 | 10888 | 10707 |
| Combustible Content of Ash | 30.42% | 25.2% | 31.8% | 25.1% | 25.7% | 31.53% | 29.87% | 33.84% | 24.46% | 47.03% | 19.02% | 6.2% | 39.4% |
| Air Temp., Boiler House | 62°F. | 73°F. | 77°F. | 74°F. | 74°F. | 70°F. | 61°F. | 59°F. | 64°F. | 62°F. | 71°F. | 76°F. | 54°F. |
| Flue Gas Temp. at Dampers (Average) | 614°F. | 540°F. | 624°F. | 671°F. | 703°F. | 708°F. | 558°F. | 630°F. | 546°F. | 677°F. | 631°F. | 662°F. | 770°F. |
| Draught at Dampers Ins. W.G. (Average) | .3" | .34" | .35" | .38" | .56" | .45" | .29" | .34" | .26" | .42" | .37" | .64" | .48" |
| Draught Main Flue Ins. W.G. | — | .69" | .7" | .64" | .73" | .7" | — | — | .75" | — | .7" | .7" | — |
| Draught Chv. Base Ins. W.G. | .52" | .88" | .89" | .9" | .93" | .96" | .68" | .62" | .92" | .7" | .86" | .84" | .72" |
| Flue Gas Analysis $CO_2$ (Average) | 6.64% | 6.54% | 7.69% | 7.51% | 7.76% | 7.98% | 7.34% | 8.78% | 7.29% | 8.67% | 8.59% | 8.41% | 10.34% |
| O (Average) | 12.6% | 12.5% | 11.83% | 11.6% | 11.52% | 11.25% | 12.15% | 10.67% | 12.25% | 10.69% | 10.76% | 11.19% | 9.2% |
| CO (Average) | Nil | Nil | Nil | .107% | .133% | .2% | Nil | Nil | Nil | Nil | Nil | Nil | .084% |
| **RESULTS OF TEST.** | | | | | | | | | | | | | |
| Coal Used/H.R. in lbs. | 800 | 900 | 1000 | 1100 | 1350 | 1200 | 806 | 932 | 913 | 1000 | 1215 | 1180 | 1350 |
| Coal Used/[f]G.A./H.R. in lbs. | 22.2 | 25 | 27.8 | 30.5 | 37.5 | 33.3 | 22.4 | 25.8 | 25.4 | 27.8 | 33.8 | 32.9 | 37.5 |
| Heat Lib./Cu. Ft. Furn. Vol./H.R. in B.T.U's. | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Evap. in lbs./H.R. Actual | 3210 | 4005 | 5022 | 5601 | 5954 | 6397 | 3561 | 4415 | 4100 | 4843 | 5530 | 6040 | 6000 |
| Evap. in lbs./H.R. from and at | 3820 | 4534 | 5655 | 6301 | 6626 | 7171 | 4113 | 5077 | 4590 | 5570 | 6230 | 6715 | 6840 |
| Evap. in lbs./H.R./lb. Coal Actual | 4.01 | 4.45 | 5.02 | 5.09 | 4.41 | 5.33 | 4.42 | 4.74 | 4.48 | 4.84 | 4.56 | 5.12 | 4.44 |
| Evap. in lbs./H.R./lb. Coal from and at | 4.78 | 5.04 | 5.66 | 5.73 | 4.9 | 5.98 | 5.1 | 5.44 | 5.04 | 5.57 | 5.13 | 5.68 | 5.07 |
| Evap. in lbs./H.R./[f]H.S. Actual | 3.84 | 4.78 | 6.0 | 6.68 | 7.11 | 7.63 | 4.25 | 5.27 | 4.89 | 5.77 | 6.6 | 7.21 | 7.16 |
| Evap. in lbs./H.R./[f]H.S. from and at | 4.57 | 5.4 | 6.75 | 7.52 | 7.9 | 8.56 | 4.9 | 6.06 | 5.5 | 6.64 | 7.42 | 8.00 | 8.15 |
| **BOILER EFFICIENCY** | **45.0%** | **45.9%** | **49.2%** | **49.3%** | **50.5%** | **52.3%** | **52.0%** | **54.0%** | **51.0%** | **53.5%** | **50.5%** | **50.6%** | **46.0%** |

| READINGS RECORDED. | HAND FIRED—NATURAL DRAUGHT | | | | | PULVERIZED COAL FIRED (Natural Draught) | | | | | PULVERIZED COAL FIRED (Natural Draught) with Soot Blowers | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | FIRED WITH FRASER & CHALMERS PATENT SOLID INJECTOR BURNERS | | | | | | | |
| | No. 14 | No. 15 | No. 16 | No. 17 | No. 18 | No. 19 | No. 20 | No. 21 | No. 22 | No. 23 | No. 24 | No. 25 | No. 26 |
| Date | 12-8-30 | 13-8-30 | 28-11-30 | 15-8-30 | 18-8-30 | 14-11-30 | 5-11-30 | 13-11-30 | 11-11-30 | 12-11-30 | 19-12-30 | 18-12-30 | 17-12-30 |
| Duration of test in hours | 8 | 8 | 8.16 | 8 | 8 | 7 | 7 | 7 | 7.13 | 7 | 7 | 7.08 | 7 |
| Steam W.P. lbs./□" Gauge Sat. | 134 | 134 | 124 | 135 | 137 | 112 | 134 | 126 | 135 | 138 | 124 | 131 | 130 |
| Water Temp. Entg. Boiler | 150°F. | 155°F. | 132°F. | 159°F. | 152°F. | 143°F. | 152°F. | 155°F. | 154°F. | 160°F. | 105°F. | 103°F. | 112°F. |
| Evaporation in lbs. (Total) | 33800 | 35900 | 41080 | 44250 | 45850 | 35256 | 36100 | 41140 | 43800 | 48800 | 36224 | 37157 | 38880 |
| Coal, Total Consumed in lbs. | 6400 | 7200 | 8000 | 8400 | 8800 | 5330 | 5688 | 6103 | 7544 | 8365 | 5595 | 5815 | 6105 |
| C.V. Gross B.T.U's. | 10300 | 9592 | 9790 | 9933 | 10550 | 11251 | 10651 | 10582 | 10256 | 10456 | 10675 | 10628 | 9751 |
| Combustible Content of Ash | 3.4% | 13.09% | 24.89% | 33.6% | 15.4% | 3.58% | 3.82% | 1.65% | 0.92% | 0.7% | NOT TAKEN | | |
| Air Temp., Boiler House | 81.5°F. | 81.5°F. | 65°F. | 79°F. | 74°F. | 59°F. | 61°F. | 59°F. | 54°F. | 57°F. | 62°F. | 61°F. | 58°F. |
| Flue Gas Temp. at Dampers (Average) | 434°F. | 477°F. | 690°F. | 520°F. | 556°F. | 606°F. | 485°F. | 682°F. | 776°F. | 863°F. | 642°F. | 592°F. | 625°F. |
| Draught at Dampers Ins. W.G. (Average) | .44" | .55" | .53" | .65" | .59" | .05" | .13" | .08" | .12" | — | .028" | .02" | .07" |
| Draught Main Flue Ins. W.G. | .83" | .81" | — | .8" | .7" | — | — | — | — | — | — | — | — |
| Draught Chv. Base Ins. W.G. | .83" | .89" | .84" | .9" | .8" | .8" | .8" | .84" | .94" | — | .53" | .6" | .6" |
| Flue Gas Analysis $CO_2$ (Average) | 6.96% | 7.15% | 7.54% | 8.95% | 8.55% | 14.46% | 12.8% | 14.67% | 13.82% | 13.85% | 15.52% | 16.45% | 16.6% |
| O (Average) | 12.06% | 12.63% | 11.49% | 10.53% | 10.89% | 4.44% | 5.76% | 4.19% | 5.19% | 5.13% | 3.395% | 2.37% | 2.21% |
| CO (Average) | .216% | .12% | Nil | Nil | Nil | .105% | .096% | Nil | .05% | .045% | .015% | .005% | .05% |
| **RESULTS OF TEST.** | | | | | | | | | | | | | |
| Coal Used/H.R. in lbs. | 800 | 900 | 981 | 1050 | 1100 | 762 | 814 | 873 | 1058 | 1196 | 800 | 822 | 872 |
| Coal Used/[f]G.A./H.R. in lbs. | 22.2 | 25.0 | 27.2 | 29.2 | 31.5 | — | — | — | — | — | — | — | — |
| Heat Lib./Cu. Ft. Furn.Vol./H.R. in B.T.U's. | — | — | — | — | — | 16300 | 16420 | 17520 | 20750 | 23700 | 16200 | 16550 | 16120 |
| Evap. in lbs./H.R. Actual | 4220 | 4487 | 5045 | 5530 | 5740 | 5037 | 5155 | 5879 | 6145 | 6971 | 5175 | 5248 | 5554 |
| Evap. in lbs./H.R. from and at | 4710 | 5000 | 5720 | 6135 | 6390 | 5642 | 5745 | 6555 | 6755 | 7720 | 6003 | 6114 | 6443 |
| Evap. in lbs./H.R./lb. Coal Actual | 5.28 | 5.0 | 5.15 | 5.25 | 5.21 | 6.62 | 6.34 | 6.73 | 5.88 | 5.83 | 6.46 | 6.33 | 6.37 |
| Evap. in lbs./H.R./lb. Coal from and at | 5.88 | 5.55 | 5.84 | 5.85 | 5.82 | 7.42 | 7.06 | 7.47 | 6.47 | 6.44 | 7.5 | 7.38 | 7.38 |
| Evap. in lbs./H.R./[f]H.S. Actual | 5.04 | 5.35 | 6.02 | 6.60 | 6.85 | 5.51 | 5.63 | 6.43 | 6.72 | 7.61 | 5.65 | 5.73 | 6.07 |
| Evap. in lbs./H.R./[f]H.S. from and at | 5.62 | 5.95 | 6.83 | 7.34 | 7.64 | 6.16 | 6.28 | 7.16 | 7.38 | 8.43 | 6.56 | 6.67 | 7.04 |
| **BOILER EFFICIENCY** | **55.2%** | **56.2%** | **57.8%** | **57.0%** | **53.3%** | **63.8%** | **64.2%** | **68.5%** | **61.7%** | **59.8%** | **68.2%** | **67.3%** | **73.5%** |

blower nozzles. These soot blowers are operated from a manifold valve which brings them into operation in their correct sequence so that the ash is blown progressively forward to the main flue. Here it is customary to install a settling chamber to avoid excessive dust emission from the stack. The ash from the front half of the fire tubes is removed through the ash doors by a rake ; this ash door can clearly be seen in the sectional arrangement.

### SIMPLIFIED SYSTEM FOR A SMALL INSTALLATION.

If the installation is only for three boilers a simplified system for distribution can sometimes be used to advantage ; such a system being shown in fig. 8. Here the bulk abstractors under the pulverized coal bin are replaced by variable speed feed screws, the number of which is equal to the number of boiler flues to be fired. After leaving the feeder the coal is fed through an injector into the primary air pipe and thence to the burner. The primary air valves are on the clean air side of the injectors and are thus not subject to any wear and tear. The type of burner used is fitted to a front plate identical with that of the solid injection burner. This burner is of very similar design to the solid injection burner except that the injector is fitted externally, whereas in the solid injection burner it is an integral part of the burner proper. Accurate control of the coal and air is again provided, as each flue has its own feeder and its own primary and secondary air valves.

### PULVERIZED COAL FIRING WITHOUT A PULVERIZER.

Dust collecting and dust extracting plants are installed at a number of collieries and with a classifying system sufficient quantities of superfine dust can often be collected to fire one or more boilers without the installation of pulverizing plant. Such an equipment can be arranged on the simplified system just described, or with the mechanical conveying system using solid injection burners.

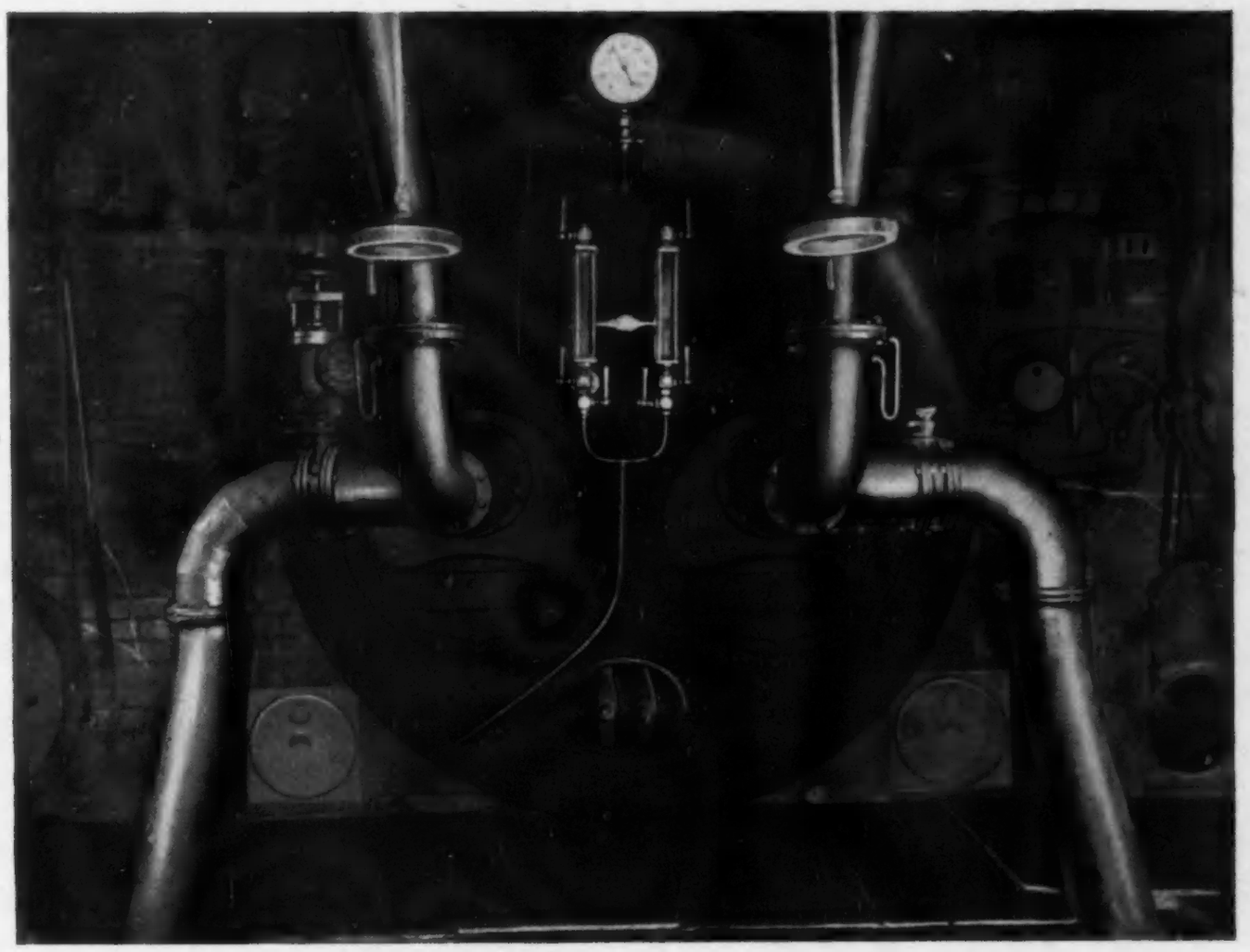


**Fig. 9.—Lancashire boiler fired by dust collected by dust-extracting plant.**

The arrangement shown in fig. 9 illustrates an actual installation which has just been completed at a colliery in the Midlands.

### RESULTS OBTAINED BY PULVERIZED FUEL FIRING.

A lengthy series of exhaustive tests have recently been completed on a boiler plant at a Works in the Midlands. Four boilers of the same size were tested under normal operating conditions, no special preparation or cleaning being allowed for any test, the object being to obtain comparative figures of normal everyday running, rather than freak test results. These results are shown in the table given on page 82, the efficiency in each case being the efficiency of the boiler having neither a superheater nor economiser fitted.

# Considerations in the Design of A.C. Moving Iron Super-sensitive Instruments.

By A. SHERWIN.

Salford Electrical Instrument Works of The General Electric Co., Ltd.

IN view of the many improvements which have recently been effected in the design of switchboard and portable instruments of the moving iron type, both as regards their consumption and accuracy, it would seem quite safe to predict that this class of instrument will eventually be used for general purposes to the almost entire exclusion of the more costly dynamometer type.

The need for a reduction in consumption has been brought about, in the case of switchboard ammeters, by the increasing demand for a reliable and robust instrument for use with modern bushing transformers to measure small currents in E.H.T. feeders, such as those of the "Grid" system. With

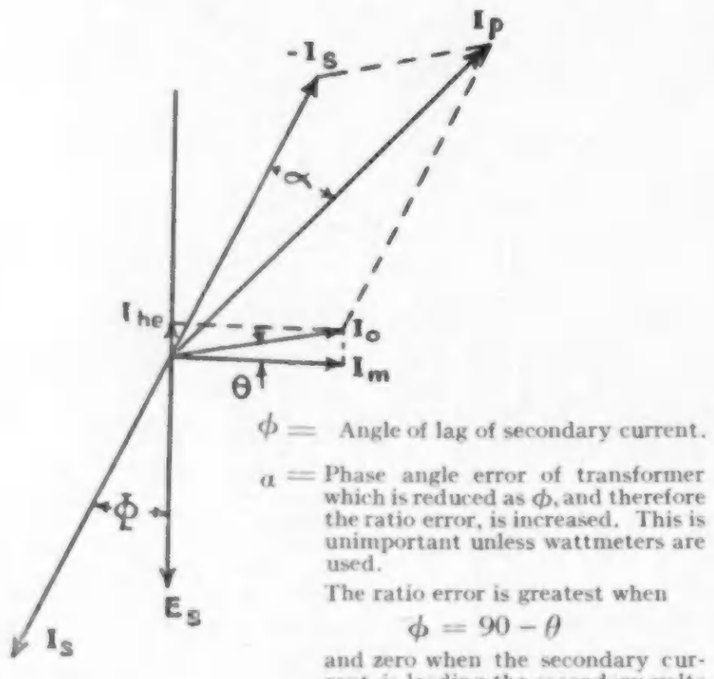

$I_p$
$-I_s$
$\alpha$
$I_{he}$
$I_o$
$I_m$
$\theta$
$\phi$
$E_s$
$I_s$
$\phi$ = Angle of lag of secondary current.
$\alpha$ = Phase angle error of transformer which is reduced as $\phi$, and therefore the ratio error, is increased. This is unimportant unless wattmeters are used.
The ratio error is greatest when
$\phi = 90 - \theta$
and zero when the secondary current is leading the secondary volts by an angle (dependent on the load), an expression for which is given in the next column.

**Fig. 1.—Vector diagram of inductively loaded current transformer.**

these transformers, the output is strictly limited by the low value of primary ampere turns, which are in turn limited by the fact that the primary conductor only passes once through its core. Although this deficiency can be neutralised by increasing the area of both core and secondary conductor (the former to increase the total flux, and in direct proportion the secondary volts, the latter to reduce the $I_S R_S$ drop) the space available for accommodating the transformer is soon used up, and subsequent improvements in ratio can only be effected by the reduction of the load applied to the secondary terminals.

It is possible, of course, to compensate for this ratio error of the transformer by calibrating each ammeter with its particular transformer, but this practice is to be avoided where interchangeability is of importance, as in the case of large distribution systems where it is desirable that an ammeter can be used with any transformer of the appropriate ratio.

For this reason, the instrument must be designed so that the volt drop across its terminals is as small as possible. This drop consists of a resistance and a reactive component of which the former is by far the larger at commercial frequencies between 20 and 100 cycles. Unless special preventive measures are introduced the reactive component may also become considerable and this would have a serious effect on the transformer ratio by causing the secondary current to lag behind the E.M.F. From the vector diagram of a current transformer shown in fig. 1, it will be seen that, in order to reduce the ratio error, the lagging power factor of the secondary circuit should be as high as possible. With a secondary current leading by an angle

$$\phi = \theta + \sin^{-1} \frac{I_o T_p}{2 I_s T_s}$$

where $T_p$ and $T_s$ are the primary and secondary turns respectively, the ratio error due to the magnetising current $I_o$ disappears, representing the ideal but impossible condition.

With an instrument giving full scale deflection with half an ampere at 50 cycles, the average figure for $\phi$ is 9 degrees, the resistance of the coil being 1.943 ohms and the inductance one millihenry at full scale deflection. With these values the *VA* consumption works out at 0.49.

The total losses in the instrument include those due to hysteresis in the magnetic material as well as those due to eddy currents, but these losses, as a portion of the total, are so small as to be entirely negligible when considering them as a contribution to the load on the transformer.

### $I^2R$ LOSSES.

The $I^2R$ losses being the most important must be the first to deserve attention. Taking a coil having a given number of turns $N$, which equals $\frac{A}{a_g}$, where $A$ is the area of coil section and $a_g$ the gross area of the conductor, the resistance of the coil, $R$, is given by

$$R = \frac{\rho N l_m}{a_n}$$

where $l_m$ is the length mean turn; $\rho$ the specific resistance and $a_n$ the nett area of the conductor.

But $\frac{a_n}{a_g}$ equals the space factor of the coil $f$,

$$\therefore R = \frac{\rho N^2 l_m}{Af}$$

and the watts dissipated, or energy lost

$$I^2R = \frac{\rho I^2 N^2 l_m}{Af} = K_1 \frac{(IN)^2}{Af}$$

$K_1$ being a constant.

It is seen that, for low losses with a predetermined number of ampere turns, the area of coil section and the winding space factor should both be as great as possible, but it was found on test that as $A$ was increased the value $IN$ had to be increased due to the distance of the outer turns from the magnetic material. At the same time the value $l_m$ increased, with the result that, as far as $I^2R$ losses were concerned, no appreciable improvement was obtained by adjusting the dimensions of the coil. The maximum space factor can be obtained by winding with enamelled or single silk covered wire, and by using the heaviest gauge possible. The latter involves a reduction of the number of turns and an increase of current, the ratio of the current transformers being chosen to suit. It is, of course, necessary to take into account the resistance of the copper connecting leads between the transformer and instrument, and as these on outdoor or E.H.T. sub-stations may be many yards in length, necessitating a restricted sectional area for economical reasons, a secondary current of half an ampere has been fixed upon, which for equal resistances of leads causes only one hundredth of the power loss as compared with the old standard 5 ampere secondary current.

While the $IR^2$ loss is practically independent of the size of coil, a small coil is to be preferred for two reasons, one being that it permits a more convenient and compact design of the movement; the other that a coil of small tunnel area has a small inductance which gives greater accuracy with small output transformers and also at higher frequencies.

### INTENSITY OF MAGNETIC FIELD AND PERMEABILITY OF MAGNETIC MATERIAL.

Whatever size of coil is used, it becomes apparent that for a sensitive instrument having the lowest possible consumption, the mass of the movement and the pivot friction must be reduced to the lowest values possible, in order that the intensity of the magnetic field which the coil has to generate may be correspondingly reduced.

The reduction of working forces is desirable in any type of instrument providing that the mass of the movement is carefully limited, the reduction of mass in the moving parts resulting in their being better able to withstand mechanical impact caused by accidentally dropping the instrument or by sudden electrical overloads.

It can be shown that the potential energy of a magnet, having an intensity of magnetisation $I_m$ and volume $v$ in a field of intensity $H$

$$= -I_m v H$$

For a small displacement of the body, $dx$, the force $F$ producing the displacement is given by

$$F = -I_m v \frac{dH}{dx}$$

If the body is soft iron, free from hysteresis and originally neutral, $I_m = kH$ where $k$ is the magnetic susceptability.

$$F = -kH \frac{v dH}{dx}$$

$$= -\frac{kv}{2} \cdot \frac{dH^2}{dx}$$

$$\text{but } k = \frac{\mu - 1}{4\pi}$$

$$\text{and } F = -\frac{\mu - 1}{4\pi} \cdot \frac{v}{2} \cdot \frac{dH^2}{dx}$$

Thus it will be seen that whatever the value of $H$, the higher the permeability of the moving body at that value of $H$ the greater will be the displacing force and therefore the torque. For a sensitive instrument, a material of large permeability at low intensity is desirable so that the copper loss in the electrical circuit can be reduced to a minimum, the ampere turns, and therefore the $I^2R$ loss, becoming reduced with the value of $H$.

The movement of the paramagnetic material into the coil increases the self inductance as the total number of lines of magnetic flux linking with the coil is increased thereby. It can be shown that the rate of change of the inductance with the angle of deflection of the moving system is a measure of the torque of the instrument at the particular value of angle chosen.

The work done in establishing a current $I$ in a circuit of total inductance $L$ is

$$W = \tfrac{1}{2} LI^2$$

where $I$ is the final value of the current.

In this case the total inductance $L$ is composed of two portions, $L_1$ and $L_2$, of which $L_1$ is the inductance at zero scale reading and can be regarded as constant; $L_2$ is dependent on the deflection of the instrument or on the movement of the magnetic

**Fig. 2. Typical G.E.C. moving iron supersensitive ammeter.**

material into the coil. The equation for work done now becomes

$$W = \tfrac{1}{2} I^2 (L_1 + L_2)$$

The torque is equal to the increase of work done with unit deflection or

$$T = \frac{dW}{d\theta}$$

from which $$T = \tfrac{1}{2} I^2 \frac{d(L_1 + L_2)}{d\theta}$$

$$= \tfrac{1}{2} I^2 \frac{dL_2}{d\theta}$$

If the rate of change of $L_2$ with angle $\theta$ is a constant, then a square law scale will result. In practice $\frac{dL_2}{d\theta}$ is a variable with $\theta$ according to the type of scale desired.

In one form of supersensitive instrument having a zero to 0.3 ampere scale reading, which has been produced by the G.E.C. Electrical Instrument Works at Salford, the maximum value of $L_1 + L_2$ which occurs at full scale deflection is only 1.2 millhenrys, while the corresponding value of $L_2$ is as great as 0.28 millihenry. Expressed in another way, the change of inductance as the pointer travels from zero to the full scale position is over 30 per cent of the minimum or zero position value.

By careful design the resistance of the operating coil has been reduced to 1.9 ohms. The calculated maximum angle of lag of the secondary current is due to the instrument alone.

$$= \tan^{-1} \frac{X}{R}$$

$$= \tan^{-1} \frac{0.377}{1.9} \text{ at 50 cycles per sec.}$$

or 11.2 degrees approx.

This value compares fairly closely with the measured angle of 11.5 degrees.

The total consumption at 50 cycles per second is 0.175 volt amperes which is an extremely small burden even for a 20/0.5 ratio bushing transformer.

The errors are very small, those due to hysteresis being practically eliminated, while the use of a moulded bakelite frame for housing the coil prevents eddy currents and their attendant errors. The high sensitivity is obtained by the use of a new magnetic material applied in the form of plates to the outside of the coil. The insertion of these plates results in a reduction of the magnetising ampere turns to one half the value required without them, while their screening action reduces the eddy currents induced in the case or in adjacent metal-work.

Refinements such as spring jewels have been adopted so that damage to pivots due to accidental impact is minimised.

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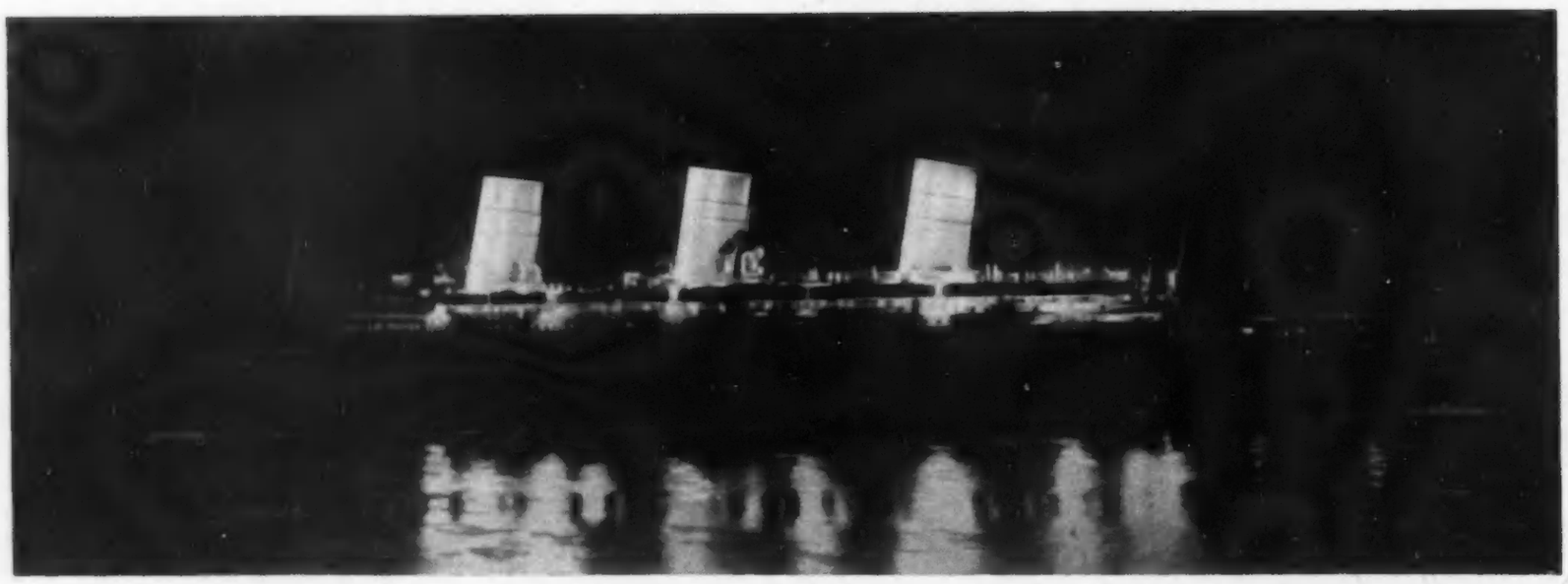
# Floodlighted Funnels on the "Empress of Britain."



**The floodlighting of the funnels of the new C.P.R. vessel "Empress of Britain" was carried out to the design of the G.E.C. Illuminating Engineering Department. Twenty-four floodlighting units are employed, each fitted with a 1,000-watt Osram lamp. The G.E.C. were also responsible for a large proportion of the lighting equipment installed in the ship, involving the use of some 22,000 lamps and a large number of lighting fittings.**

# High Tension Overhead Transmission Line Fittings.

PART I.

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Overhead Transmission Dept. of The General Electric Co., Ltd.

*This is the first part of an article dealing with a most important aspect of overhead line construction, the design of the various fittings employed for the suspension of the line and earth conductors.*

*In Part* I. *the author outlines the latest designs of Suspension Clamps and this will be followed in a later issue by Part* II., *in which he will deal with Tension Clamps and Joints.*

IN any design of overhead transmission line the mechanically weakest and most delicate points of the line and earth conductors are those where they are suspended, tensioned or jointed, as the case may be. The various fittings employed for this work consequently require very careful design, involving a study of several factors, chief among which are climatic conditions, conductor material and the importance of the particular line under construction.

It is therefore proposed in these articles to describe in some detail the design of the principal fittings which in practice have been found to give the most satisfactory results. These fittings comprise the suspension and tension clamps which secure the line conductors to the insulator strings, the earth conductor suspension and tension clamps and the line and earth conductor joints.

## I. SUSPENSION CLAMPS.

The essential features which a good design of suspension clamp must possess may be summarized as follows :—

1. The fitting must have adequate slip strength.
2. The clamping arrangement must not damage the surface of the conductor.
3. The shape of the clamp and the clamp mouth must be such as to fit the sag curve of the conductor and any kinks in clamping the conductor must be avoided.
4. The injurious effects of conductor vibration must be reduced to a minimum.
5. Corrosion due to electrolytic action at the points of contact of different materials must be eliminated.

These main requirements are discussed in detail below.

### SLIP STRENGTH.

A high slip strength is required in order to guard against the possibility of the conductor slipping through the clamp due to the setting up of unbalanced loads in two adjacent spans. This condition may be produced by unbalanced ice loadings. In such a case, if the slip strength of the clamp is inadequate, the conductor will slip through the clamp and remain in its new position after the unbalanced load has disappeared, thereby producing too big a sag in one span with the possibility of an excessively high conductor stress in the other should it again become loaded with ice. It is also necessary that in the event of a conductor breaking in one span the conductor in the adjacent span shall not slip through the clamp to any great extent, for the following reasons :—

(*a*) To avoid serious damage to the conductor.
(*b*) To reduce the time of repairs to a minimum.
(*c*) To prevent the conductor from sagging too near the ground in the adjacent spans, thereby becoming a source of danger to life ; also to avoid damage to the conductors by burning were they to touch the ground.

For important main transmission lines between large power stations and for feeder lines in areas taking a heavy load (*i.e.*, for 66 kV, 132 kV or higher voltage lines) a slip strength of about 25 per cent. of the ultimate breaking strength of the conductor may be regarded as sufficient. For less important lower voltage lines having a comparatively small conductor section and smaller spans, a slip strength of 1,000 to 1,400 lbs. will meet the requirements.

### DAMAGE BY CLAMPING AND CORROSION.

The clamping device must avoid any damage to the conductor strands at the clamping point. In order to ensure this, the conductor is protected by a tape wrapping inserted between the conductor and clamp and extending about 6ins. beyond the clamp on each side. The size of the clamping device is designed to give a comparatively low clamping pressure at the required slip strength. The tape is made of the same material as the

conductor itself in order to avoid the corrosion of the strands by electrolytic action which would result when dissimilar metals are in contact. The body of the clamp is usually made of galvanized malleable iron.

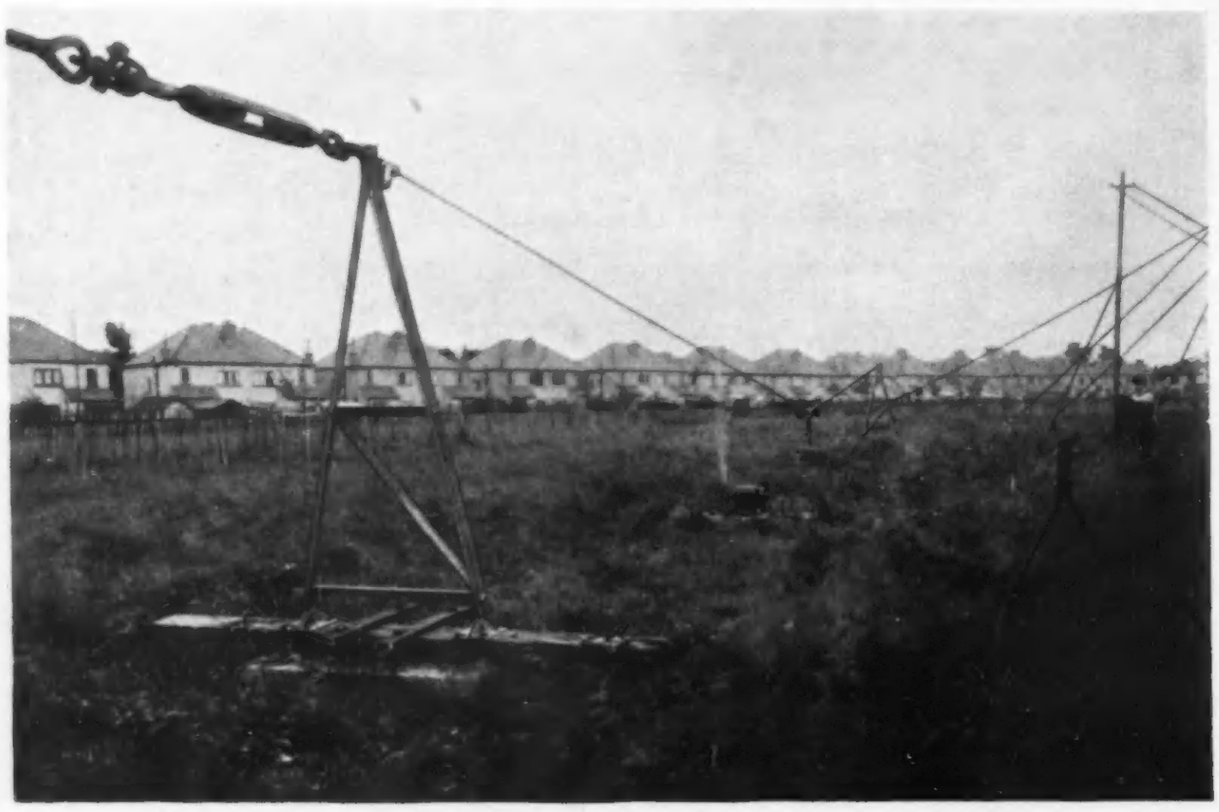

**Fig. 1.—Vibration test being carried out on steel-cored aluminium conductor at the G.E.C. Research Laboratories Wembley, England.**

The present day practice of using a tape for protecting the conductor instead of the aluminium or copper liners used in the past, has the great advantage of reinforcing the conductor where it passes through the clamp, thereby strengthening it against the effects of vibration.

### SHAPE OF THE CLAMP.

The shape of the internal surfaces of the clamp must be so formed that the conductor is not forced into any sharp kinks either inside the clamp or at the clamp mouth. Any sharp change of direction would result in "bird caging" of the strands and would incur considerable weakening. The mouth piece of the clamp must be designed to allow the conductor to follow its natural sag and must also allow for the bending of the conductor under vibration, without producing unduly high stresses.

### ALLOWANCE FOR VIBRATION.

The theoretical and experimental investigations carried out by various authorities in connection with conductor vibration problems have resulted in the following conclusions.

(*a*) Conductor vibration is caused by air eddies forming on the lee side of the conductor when it is acted upon by a transverse wind. These eddies result in an alternating force which tends to start and then maintain vibration in a vertical plane.

(*b*) The frequency of vibration depends upon the wind velocity and the diameter of the conductor.

(*c*) The wavelength is dependent upon the ratio between the mechanical stress in the conductor and its weight.

(*d*) The amplitude of vibration depends upon the magnitude of the forces to which the conductor is subjected by the air eddies and also on the internal friction resistance of the cable itself, this resistance being dependent on the construction. The amplitude is also a function of the wave length.

Vibrations observed on lines in service have either a low frequency, large amplitude and long wavelength or a high frequency, small amplitude and short wavelength. The former is less injurious to the conductor than the latter, as high frequency vibrations result in the conductor strands becoming damaged in a much shorter time. Conductors vibrate mainly in the form of standing waves, the suspension and tension points being nodes.

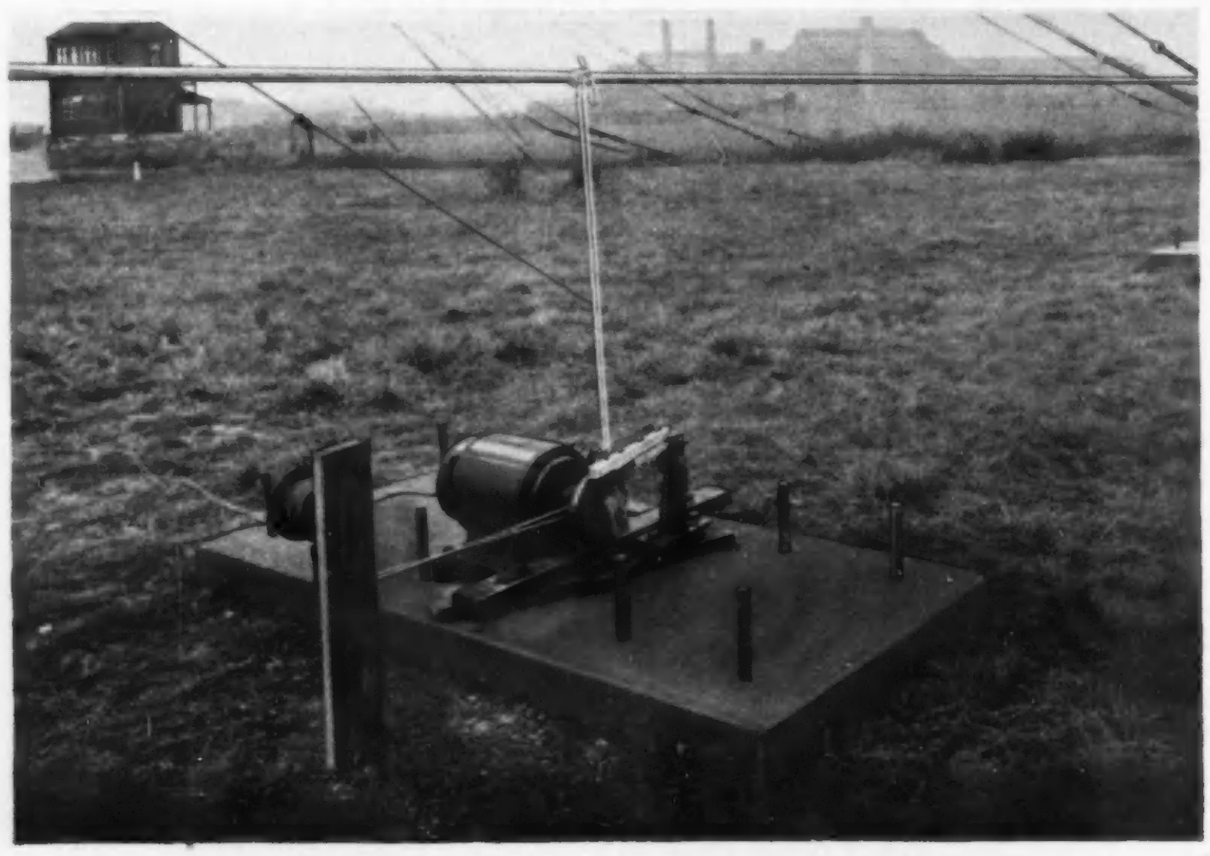

**Fig. 2.—Vibrating mechanism used for the test illustrated in fig. 1.**

Due to vibration, the conductor is subjected to additional longitudinal alternating stresses. These additional stresses are obviously greater at the suspension and tension points than elsewhere and may cause breakage of the strands due to fatigue. Most of the

failures on conductors in service have been observed at suspension clamps and very few at strain clamps.

In this article we are concerned only with the minimising of conductor fatigue failure by improvements in the design of clamps, but there are of course other remedies such as the provision of special vibration dampers, the use of line conductor material having a high vibration resistivity, the employment of a comparatively low conductor working load, etc.

Experience has shown that fatigue failures occur mainly on steel cored aluminium conductors and conductors of pure aluminium, or aluminium alloys, and very seldom on copper conductors. It has also been observed that more vibration failures occur in countries where the lines are not designed for ice loading because in such cases the conductors may be subjected to a higher normal stress.

A large number of vibration tests have been carried out for the purpose of studying the forms of vibration encountered under varying conditions and of developing the most efficient type of clamp to withstand them. For some of these tests a special vibration testing plant has been installed at the G.E.C. Research Laboratories, Wembley, England, on which a conductor length of over 250 ft. can be vibrated, if required.

A vibration test on suspension and tension clamps for steel-cored aluminium conductors is shown in fig. 1. In order to obtain conditions equivalent to those experienced by a suspension clamp in actual service, a weight corresponding to the pull in the suspension insulator string is suspended from an inverted clamp. The vibrating mechanism used is shown in fig. 2.

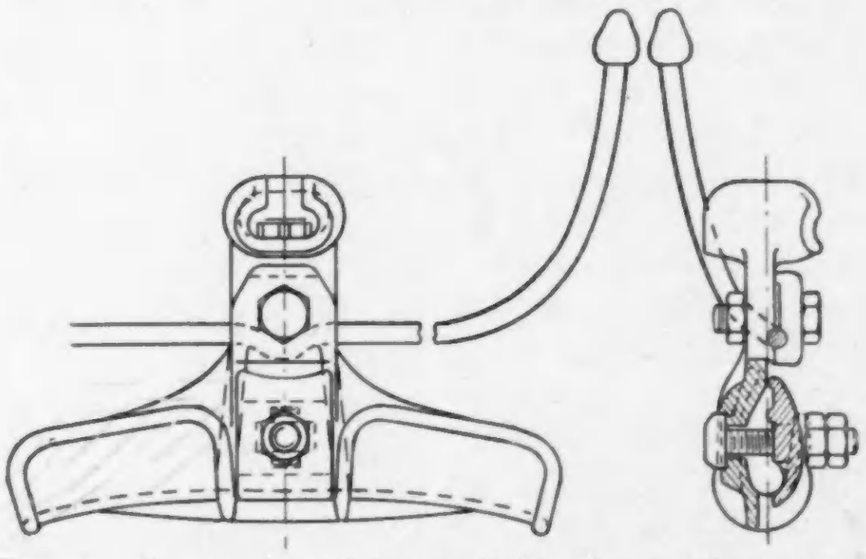

**Fig. 3.—Suspension clamp suitable for conductors on secondary lines up to 0.456in. diameter.**

As a result of such tests, the suspension clamps shown in figs. 3 and 4 have been found suitable for the less important lines and can be used for copper, aluminium or steel cored aluminium conductors ; the clamp shown in fig. 3 being suitable for the smaller size conductors up to 0.456 in. diameter, and that in fig. 4 for larger sizes. The body of the clamp is made of galvanized malleable iron, the conductor being protected against both electrolytic corrosion and damage due to squeezing by a tape of the same material as the conductor. The slip strength of these two types is from 1,100 to 1,320 lbs.

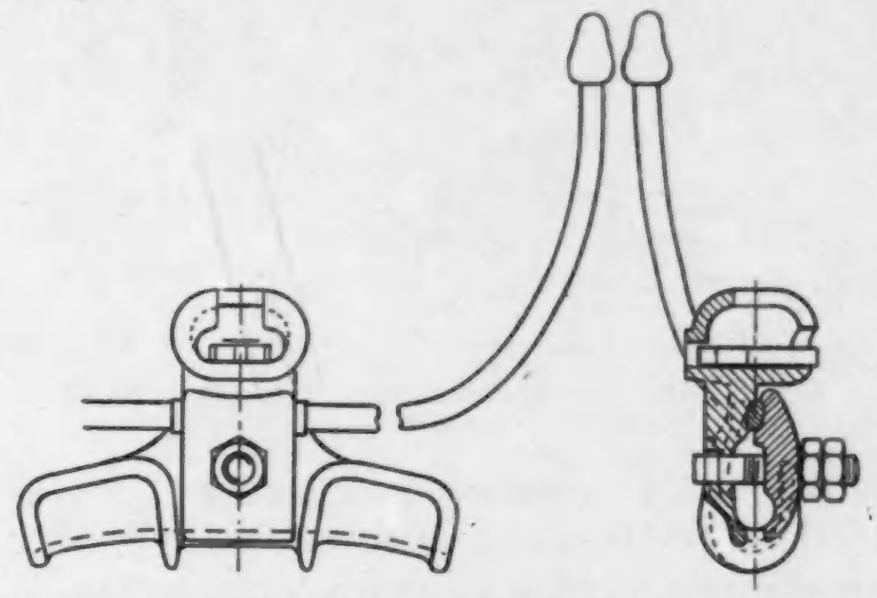

**Fig. 4.—Suspension clamp suitable for conductors of sizes over 0.456in. diameter.**

The socket connector is combined with the clamp in order to keep the overall length of the suspension string as short as possible. This design also allows for the fitting of an arcing horn between the cover plate and the body of the clamp so that the conductor may be protected from the influence of a power arc on the insulator string. As will be seen from figs. 3 and 4, the ends of the horn are bent out of the vertical plane so as to avoid damage to the conductor by liquid metal dropping from the ends of the horn during a power arc. These two designs fulfil all the requirements mentioned at the beginning of this article with the exception of that relating to vibration effects. With heavily vibrating conductors they are not so efficient as those described below. It is advisable, therefore, to use them only on lines in which heavy vibrations are unlikely to occur.

The suspension clamps shown in figs. 5 and 6 can be employed for all lines except hollow-conductor lines. In designing these types the chief aim has been to avoid fatigue failure of the conductors due to vibration. During the course of a large number of vibration tests on different types, it was found that clamps of the designs shown in figs. 5 and 6 were able to withstand the highest number of vibrations before failure of the strands occurred. The tests have shown that one of the main points is to keep the weight of the clamp body as light as possible in order to enable the clamp to follow the vibrations, thus reducing additional stresses in the conductor to a minimum and keeping the radius of curvature of the conductor at the mouth of the clamp as large as possible.

Special suspension arrangements of the clamp body have been developed. In fig. 5 the point of suspension is on the level of the centre-line of the

conductor and consists of two trunnions combined with the clamp body. Connection to the suspension string is made by two links, as shown, and a socket connector. Arcing horns, or guard rings, are attached

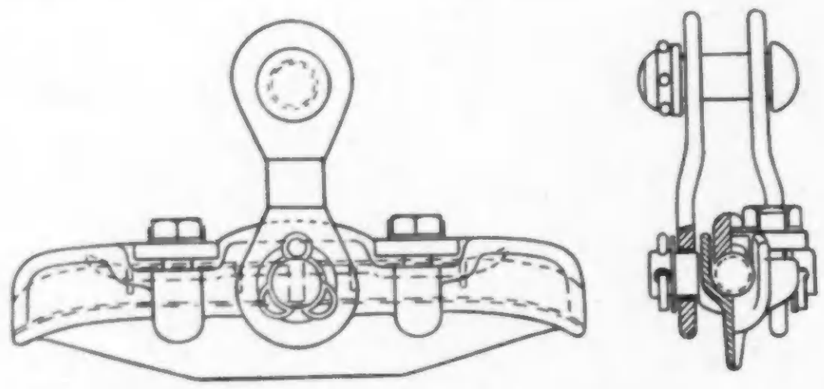

**Fig. 5.—Illustrating suspension arrangements of the clamp body.**

to the socket connector and therefore have no effect on the behaviour of the clamp body when vibrating.

The suspension arrangement in fig. 6 is a modification of the arrangement in fig. 5, the point of suspension being moved from the centre-line to the level of the top of the conductor, this point being approximately at the level of the intersection of the tangents to the sag curves. The clamp body is supported on knife edges. These two features greatly increase the mobility of the clamp. The conductor lies on a smooth curve in the clamp body, the long cover plate of which ensures a comparatively low pressure on the conductor. Here again as a protection against corrosion and also to reinforce the conductor through the clamp, a tape is used. The reinforcing of the conductor by special means, such as the use of wire rods of round or square

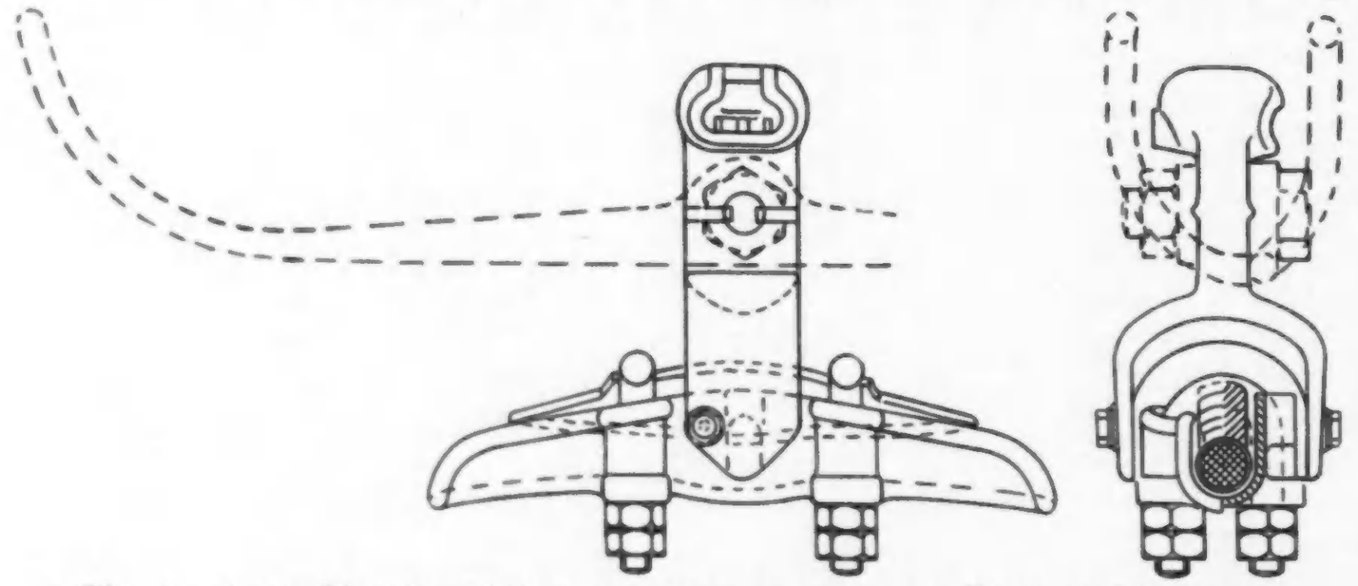

**Fig. 6.—A modification of the suspension arrangement illustrated in Fig. 5.**

section from the clamp to the ends, increases the resistivity of the conductor at the clamp considerably, but the best test results were obtained with the arrangement shown in fig. 7.

The clamp illustrated in fig. 7 is similar to that in fig. 6, but a steel spring is placed under the conductor extending about two feet on each side of the clamp, the ends of the spring being fixed to the conductor by small light clamps. For very large conductors the springs are longer and may consist of flat strips of spring steel of different lengths. The conductor is protected by a tape over the whole length of the spring. This arrangement, while providing a perfectly flexible support for the conductor, gives a good distribution of the energy of vibration and reduces the curvature of bending. The following test figures show the high efficiency of this device.

Clamp shown in :—

Fig. 5—4 million to 5 million vibrations.
Fig. 6—5 million to 6 million vibrations.
Fig. 7—80 million to 100 million vibrations.

These figures give the number of vibrations which the conductor was able to withstand before damage to any of the strands was observed. It should be

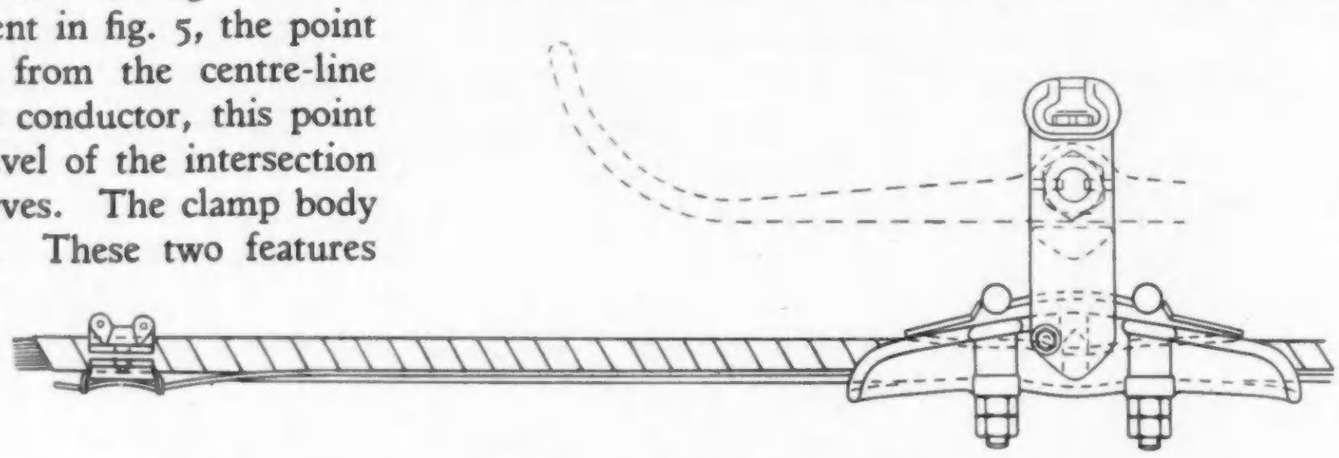

**Fig. 7.—Clamp with a steel spring placed under the conductor.**

pointed out, however, that these figures can only be used for comparing the three types of clamp, and should not be compared with other test results carried out under different conditions, as the results of vibration tests depend to a very great extent on the particular test conditions, such as the tension in the conductor, amplitude, wavelength, etc. In carrying out the above tests the conditions for all three types of clamp were the same.

All the clamps shown in figs. 5, 6, and 7 have a slip strength of at least 25 per cent. of the ultimate strength of the conductor, the clamp bodies being of galvanized malleable iron. In figs. 6 and 7 the suspension link is combined with the socket connector for economic reasons, and to keep the overall length of the insulator string as short as possible. Any arcing horns or guard rings are connected to the socket connector. These suspension clamps fulfil all the requirements set out at the beginning of this article.

### II. SUSPENSION RELEASE CLAMPS.

The suspension clamps already described hold the conductor without slipping until the stress is about 25 per cent. of its ultimate breaking load. When using these clamps the towers must be capable of withstanding the mechanical shock and torsion load caused by the breaking of a conductor. In order to avoid the subjection of straight line towers to very high torsional loads under broken conductor conditions, devices known as "release clamps" have been developed, the main feature of which being that they allow the conductor to slip through the clamp at a definite unbalanced load or at a definite angle of deviation of the suspension string from the normal position. If a conductor breaks, the tension in the adjacent spans is therefore immediately reduced to an amount which the towers can safely withstand.

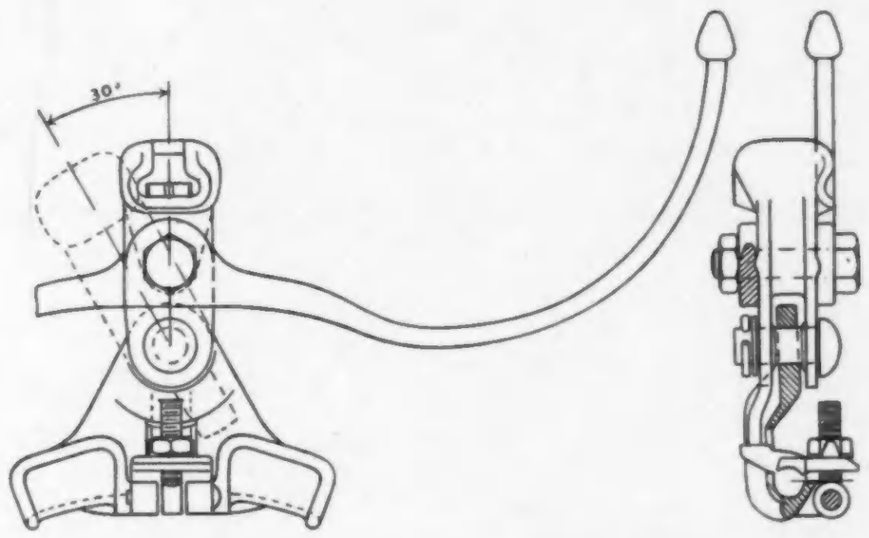


**Fig. 8.—A "release" clamp which allows the conductor to slip through at a definite unbalanced load.**

In fig. 8 is shown one construction of a release clamp. In the normal vertical position the cover plate holding the conductor rests on an extension piece of the socket connector attached to the clamp by a bolt. Under broken conductor conditions the suspension string swings into the span and as soon as the angle of deviation reaches 30 degrees, the extension piece of the socket connector slips off the cover plate leaving the conductor free to slip through the clamp.

The longitudinal pull necessary to release the cover plate is about 330 lbs. In order to prevent the conductor slipping right through, an auxiliary clamp (as shown in fig. 9) may be attached to the conductor at a distance of about two to three yards from each side of the release clamp. The slipping of the conductor through the clamp for two to three yards is sufficient to reduce the conductor tension in the adjacent span to a safe figure. In the normal vertical position (up to 30 degrees deviation) the slip strength is approximately 1,320—1,500 lbs. There is therefore no reason to fear that the conductor will be released by small unbalanced loads such as unbalanced ice-loadings or a difference in levels of the supports.

Another construction of a release clamp is illustrated in fig. 10. When this clamp is in the

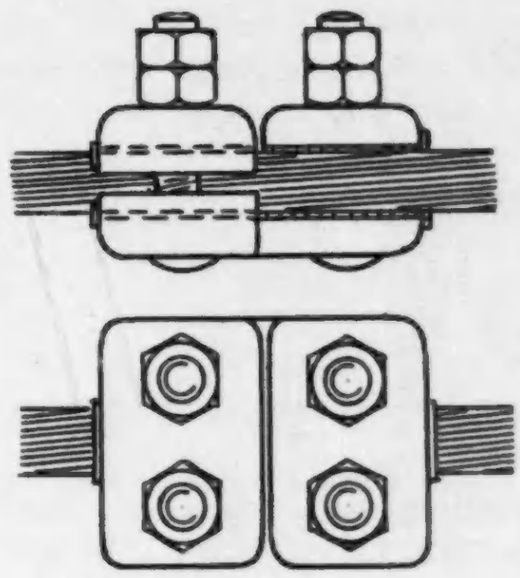

**Fig. 9.—The "auxiliary" clamp prevents slipping of the conductor right through the "release" clamp.**

normal vertical position the conductor is secured by a rounded clamping piece which imparts a light bend to the conductor with the result that it is held by friction at points A, B and C. The clamp can swing 10 degrees out of the vertical without the clamping piece moving. If the conductor breaks the pressure at A, B and C is released and the conductor slips through, but at 45 degrees, the clamping piece acts as a brake and prevents the conductor from being completely released. The additional auxiliary clamps mentioned above are therefore not necessary with this type of release clamp.

### III. EARTH CONDUCTOR SUSPENSION CLAMPS.

The same types of clamp described in Sections I and II may be used for suspending the earth

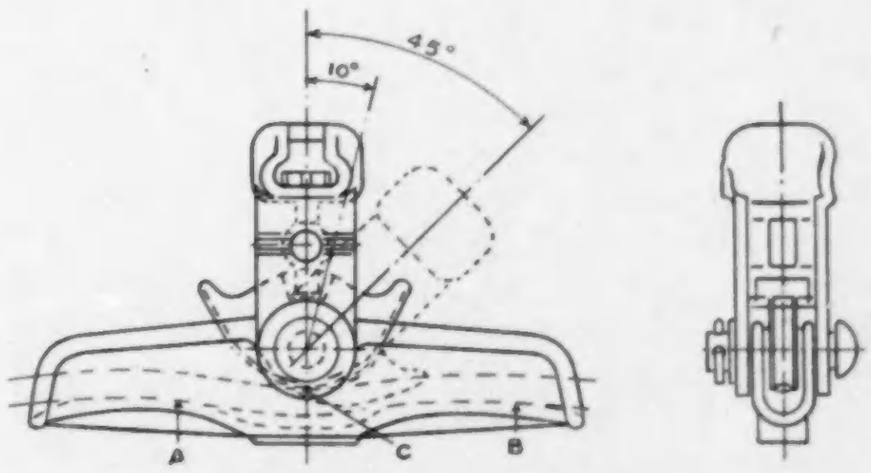


**Fig. 10.—Another form of "release" clamp.**

conductor on straight line towers. A typical earth conductor suspension arrangement with normal type of suspension clamp is shown in fig. 13. In order to obtain good electrical contact between the earth conductor and the steel tower a special flexible copper bonding strip is used.

Fig. 11 shows a special type of earth conductor suspension clamp for straight line towers, which consists of a support for the standard suspension clamp illustrated in fig. 5. It eliminates the effects of vibration, and has the further advantage of reducing not only the height of the tower but also the bending moment resulting from the load on the earth conductor. For tension towers a swivel fitting

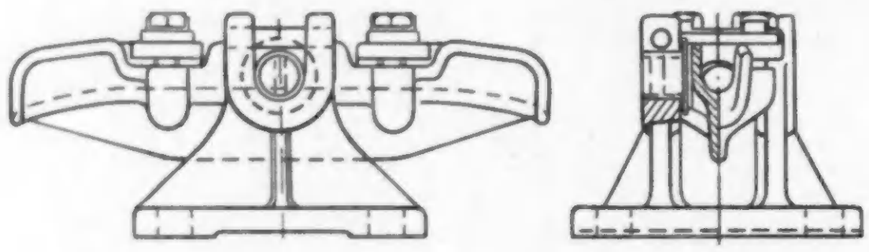

**Fig. 11.—Special type of earth conductor suspension clamp consisting of a support for the standard clamp illustrated in fig. 5.**

is used and is attached to the top of the tower by four bolts. The earth conductor is held by means of two standard earth clamps which are attached to the swivel fitting by an extension link. A bonding clamp is incorporated to give good contact with the tower.

In fig. 12 is shown an earth conductor clamp for use on intermediate straight line towers, which is fixed rigidly to the tower. This type of clamp is only recommended for use with high quality steel or bronze earth conductors.

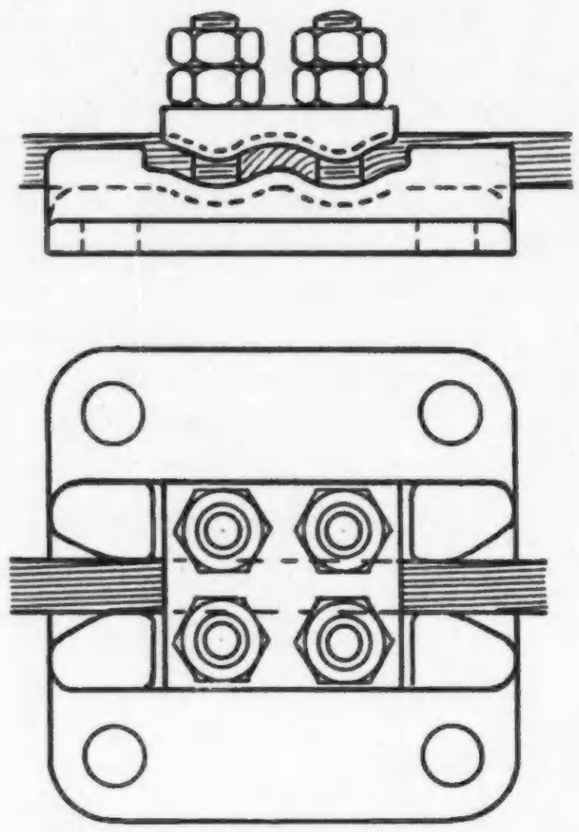

**Fig. 12.—Earth conductor clamp for use on straight line towers.**

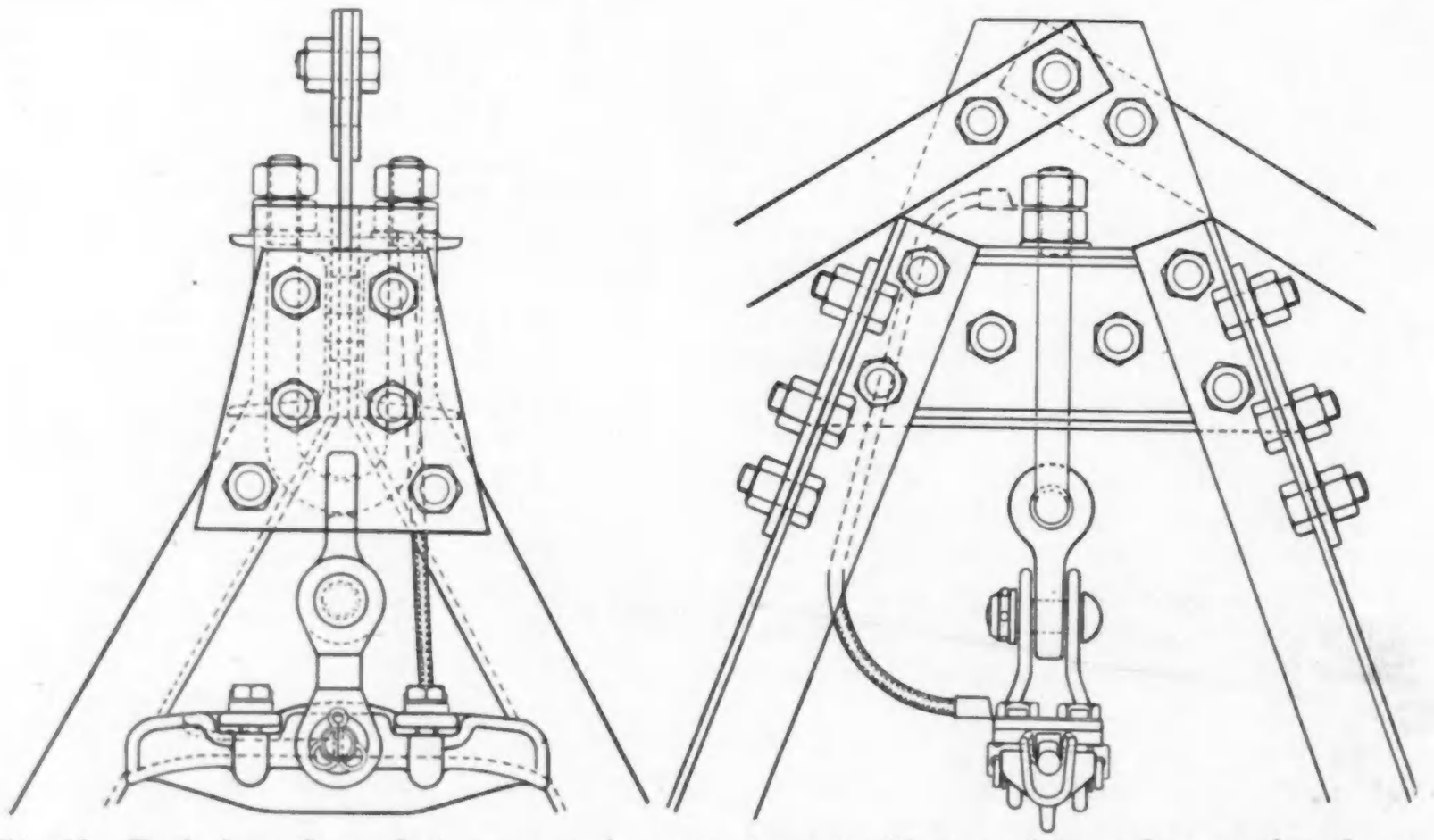

**Fig. 13.—Typical earth conductor suspension arrangement with normal type of suspension clamp.**

# Notes on the Application of Induction Motors to Industrial Drives.

By W. P. RICHARDSON, A.M.I.E.E.
Design Dept., Witton Engineering Works of The General Electric Co., Ltd.

WITH the rapid standardization in Great Britain of all electrical supplies to a uniform 3-phase, 50-cycle system, involving the replacement of large numbers of electric motors, the problem of the type and size of motor best suited for a particular drive is constantly arising. The following notes have therefore been prepared with a view to assisting engineers responsible for the installation of A.C. motors. The particular drives dealt with, although by no means an exhaustive selection, are representative of those most commonly encountered in practice, while reference to the characteristics of the motors discussed will probably enable problems associated with other forms of drive to be solved.

Examination of the characteristics of motors and driven machines shows that the chief point for consideration is the torque required during acceleration from rest up to full speed, while a further important point is the amount of current drawn from the supply at starting. It therefore follows that not only motors but also their starting gear must be considered.

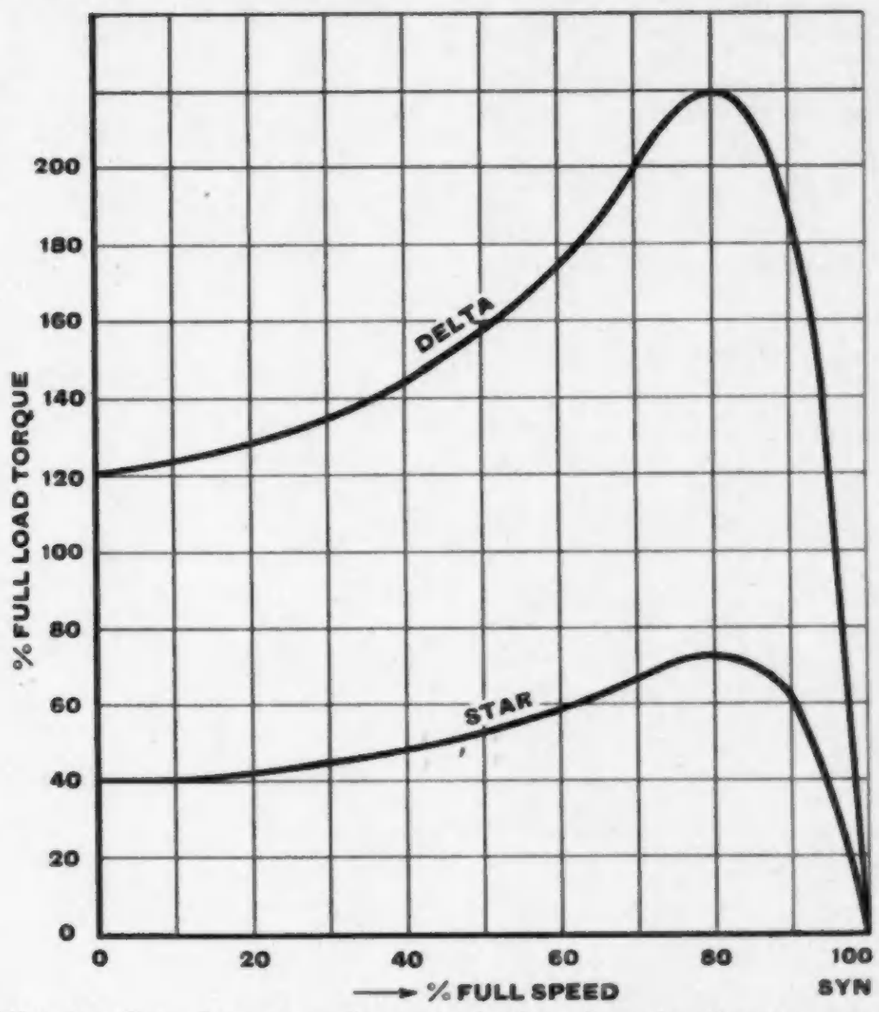


Fig. 1.—Speed-torque characteristics of squirrel cage motor.

## SQUIRREL CAGE AND SLIPRING MOTORS.

The two principal types of induction motor, squirrel cage and slipring, are well known, their fundamental difference being that while the squirrel cage has a rotor of fixed electrical characteristics, and consequently fixed starting and running performance, those of the slipring motor may be varied over a very wide range by the insertion of resistance in the rotor circuit. This is clearly illustrated in the accompanying diagrams, figs. 1, 2 and 3.*

The chief advantage of the squirrel cage motor is the comparative simplicity of the rotor construction, enabling a robust and cheap machine to be made. Its disadvantage lies in its fixed characteristics, rendering the machine incapable of changing its starting performance except by altering the applied volts per phase. The chief advantage of the slipring motor is its flexibility which, however, necessitates a more expensive form of construction than the squirrel cage type.

## HIGH TORQUE SQUIRREL CAGE MOTORS.

During recent years various types of squirrel cage motor have been developed which give a higher starting torque per ampere starting current than the standard squirrel cage type. This result has been obtained in two ways, by

1. High resistance rotors.
2. Double-deck, or Boucherot rotors.

The first type may be made with a standard type of rotor winding having either a reduced section, or made of a high resistance material. Such an arrangement gives a good current/torque ratio, and a power factor equal to that of a standard type of motor, but on account of the increased rotor loss, the efficiency is reduced. This arrangement is most suitable for duties involving frequent starting and only comparatively short periods on load. The second type is made with a rotor having two windings, an outer winding having a high resistance and low reactance to give the required starting characteristics, and an inner winding having a low resistance and high reactance, which carries the major portion of the current on full load. This type has an efficiency equal to that of a standard type of motor, but the power factor is lower, particularly where too low a current/torque ratio is aimed at, and also in the case of slow-speed motors. For motors of normal speeds of 1,500, 1,000, 750 and 600 r.p.m., with outputs of about 4 h.p. per pole and upwards, the

* c.f. Theory and Design of the Polyphase Induction Motor. S. P. Smith D.Sc., page 315.

power factor will not, as a rule, be appreciably below that of a corresponding slipring motor, and thus the double-deck motor gives the most satisfactory arrangement for continuously rated motors of the more commonly used sizes. Where slow speed high torque motors are required, probably the best

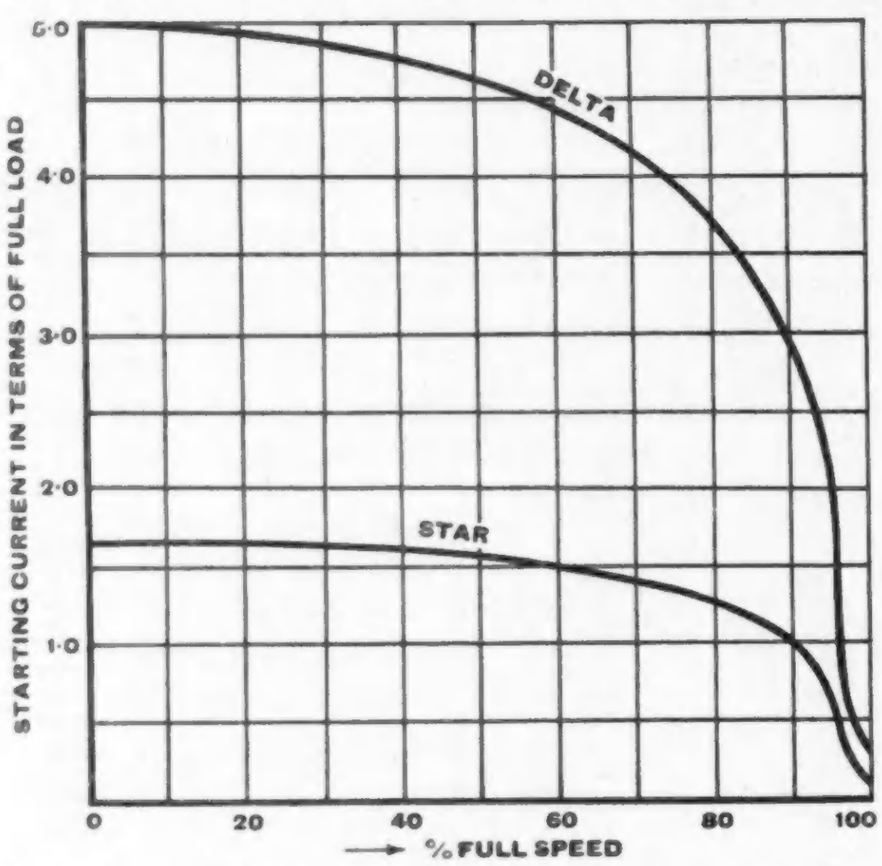


**Fig. 2.—Speed-current curve of squirrel cage motor.**

arrangement is a motor with a high resistance rotor, suitably designed in a larger frame to allow the stator copper and iron losses to be reduced to offset the increased rotor loss.

In fig. 4, "A" is the speed-torque curve for a double-deck rotor and "B," the speed-current curve. The corresponding speed-torque curve for a straight squirrel cage motor, included for comparison, is shown by "C."

Speed-torque characteristics can be altered in shape by different proportions of the rotor slots.

### METHODS OF STARTING.

Since the type of motor selected for any particular drive depends to a great extent on the conditions obtaining at starting, some mention may be made of the usual starting methods.

1. Slipring motors are started by the familiar rotor resistance starter, which may be either of the simple hand operated type, or automatically operated by means of contactor gear. In the latter case the motors may be operated by means of a push button, limit switch, float switch, etc., situated at the most convenient point of control, whether close to the motor or at a distance.

2. Squirrel cage motors may be started by switching direct on the line. This is the simplest method but is usually limited to smaller sizes, as explained later. Occasionally they are started by a resistance starter in series with the stator, the simplest arrangement being a star connected stator with the starter in the neutral. Although this method is not efficient, the current required for a given torque being high, it finds a certain field of use with small hoist motors and the like. A more frequently used method is starting by auto-transformer.

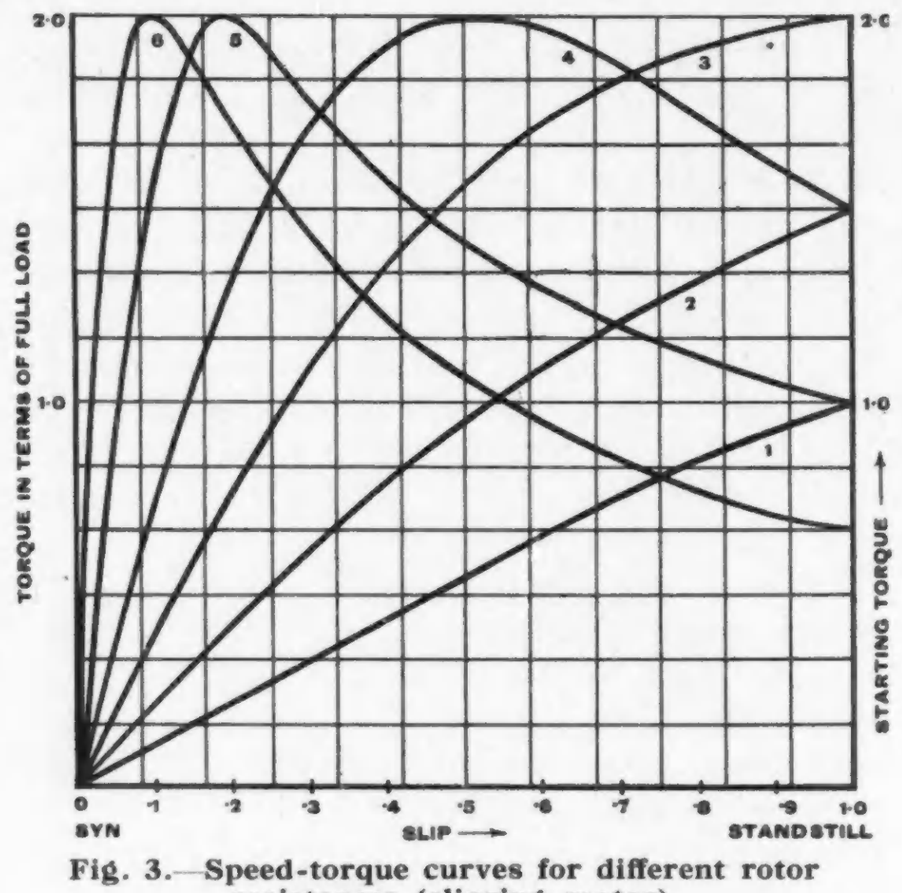


**Fig. 3.—Speed-torque curves for different rotor resistances (slipring motor).**

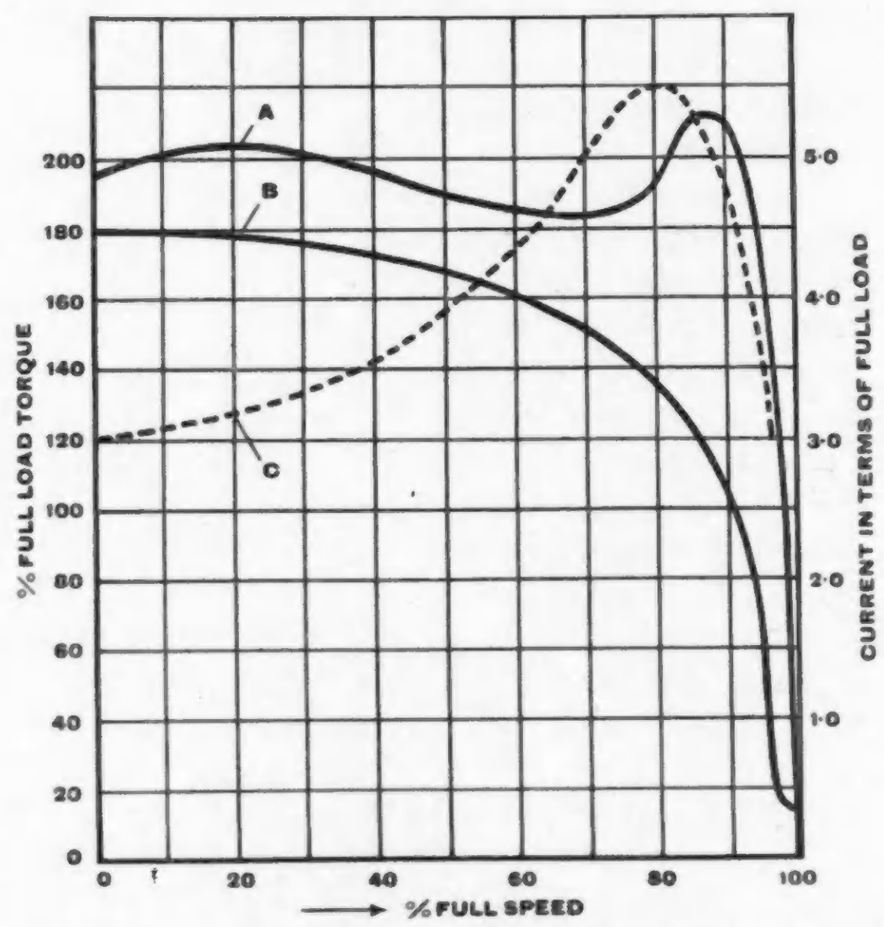


**Fig. 4.—Characteristics of high torque squirrel cage motor. A—Speed-torque curve; B—Speed-current curve; C—Speed-torque curve of a straight squirrel cage motor.**

In this method a reduced voltage is applied to the stator winding at starting; this reduces the current in the motor from its full short-circuit value in proportion to the voltage on the tapping, and the current from the line and starting torque in proportion to the square of the tapping voltage. This method is suitable for either hand operation

or contactor control. One method of connecting an auto-transformer, showing the relative values of pressure and current, is shown in fig. 5*a*, while fig. 5*b* illustrates the values of the current in the motor, starter and line.

Probably the most common method of starting squirrel cage motors is by means of star-delta starters. It is not always recognised that this is a simple mechanical arrangement which gives the same results as an auto-transformer starter on $\frac{I}{\sqrt{3}}$, or 58 per cent. tapping, but is simpler, cheaper and draws no magnetising current. The arrangement of the windings and values of volts and current per phase with this method are given in fig. 6, which also shows how the torque and current are one-third of the values obtained by direct switching. It should be noted that, in order to use this method, the motor must be suitably wound to run mesh-connected and must have both ends of each phase brought out, whereas for direct switching, or auto-transformer starting, the stator may be either star or mesh, only three leads being necessary.

### THE SELECTION OF A SUITABLE TYPE OF MOTOR AND STARTER FOR A PARTICULAR DUTY.

This is a problem which has always to be faced when new plant is being installed, and it is proposed to discuss it in the main, from two points of view:—

1. Starting current.
2. Load conditions and duty.

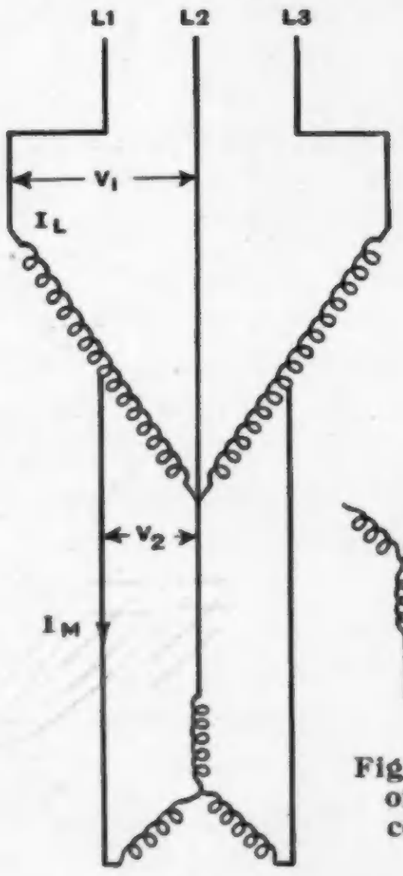


**Fig. 5a** (*Left*).—**Connection diagram for auto-transformer starter. Open delta.**

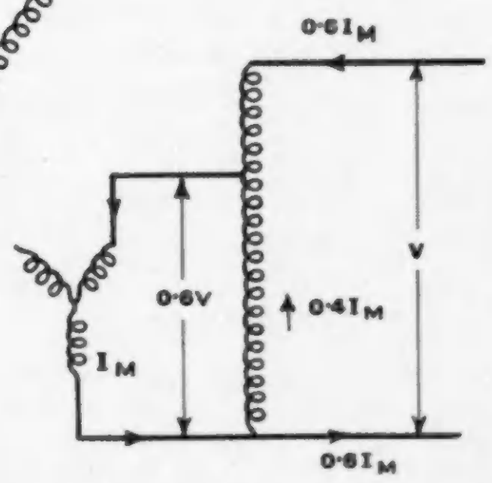


**Fig. 5b** (*Above*).—**Relative values of current and voltage for 60 per cent. tapping.**

1. *The Selection of Suitable Motor and Starter from the Point of View of Permissible Starting Current.*—The permissible starting current may vary considerably in different cases. The determining factors are the horse power of the motor concerned and its position on the supply system, *i.e.*, whether on a main feeder close to the source of supply, or on a feeder in an outlying district; whether the consumer takes a small amount of power at low pressure, or a bulk H.T. supply. In all of these factors the supply authority is interested and will legislate accordingly.

In the case of low tension public supply, the largest squirrel cage motor which is allowed to be

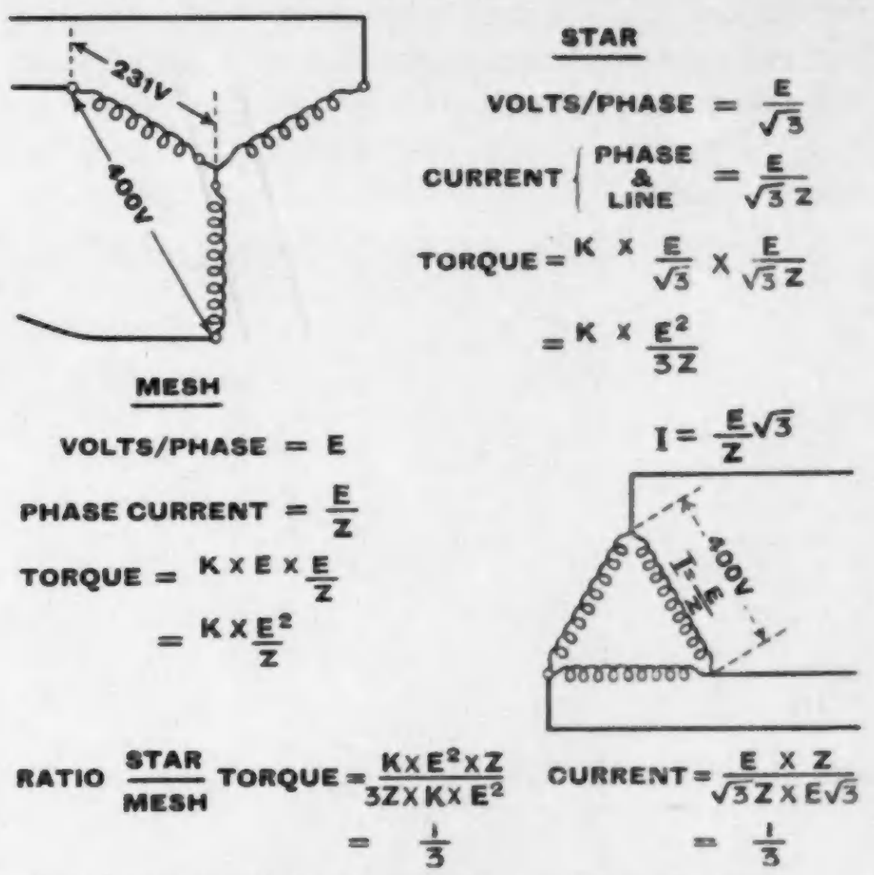


**Fig. 6.—Illustrating relative values of torque and current for star-delta starting and direct switching.**

switched direct on the line may be as low as 3 h.p. Where a bulk high tension supply is taken, an appreciably higher limit is permissible, the actual size depending on the total value of the load. In power stations, for example, and on private supplies, *i.e.*, collieries, works, etc., the limit for direct switching is often quite high—100 h.p. and more.

In the case of public supply lines, where the torque required at starting is of the order of 40 per cent. F.L.T., and a current of about 1.75 × F.L.C. is permissible, a squirrel cage motor with star-delta starter is generally found to be suitable. If a torque of 60 to 70 per cent. F.L.T. is required with similar limits of current, then a high torque motor with star-delta starter will be necessary. Alternatively, if the starting current is not too limited, a straight squirrel cage motor with auto-transformer starter will give a higher operating p.f. but with a higher initial cost for the starter. Motors of the order of 3 h.p. may usually be switched direct on the lines, as already mentioned. Where, owing to the size of the motor, the starting current must be kept to a relatively low value, or where a heavy starting torque is required, a slipring motor is necessary.

If a bulk H.T. supply is taken, motors of the order of 20 h.p. or more may usually be switched direct on the line, while larger squirrel cage motors may be started by star-delta or auto-transformer starters, according to the torque required, as indicated above.

2. *The Selection of a Suitable Motor and Starter from the Point of View of Load Conditions.*—In the following analysis of the requirements of various drives, any restrictions as to starting current are ignored. Here, again, while some applications fall definitely into a particular category, many are on the border line and no hard and fast rule can be given. For the sake of clearness the drives are divided into two groups; (*a*) those suitable for slipring motors, and (*b*) those suitable for squirrel cage and high torque motors.

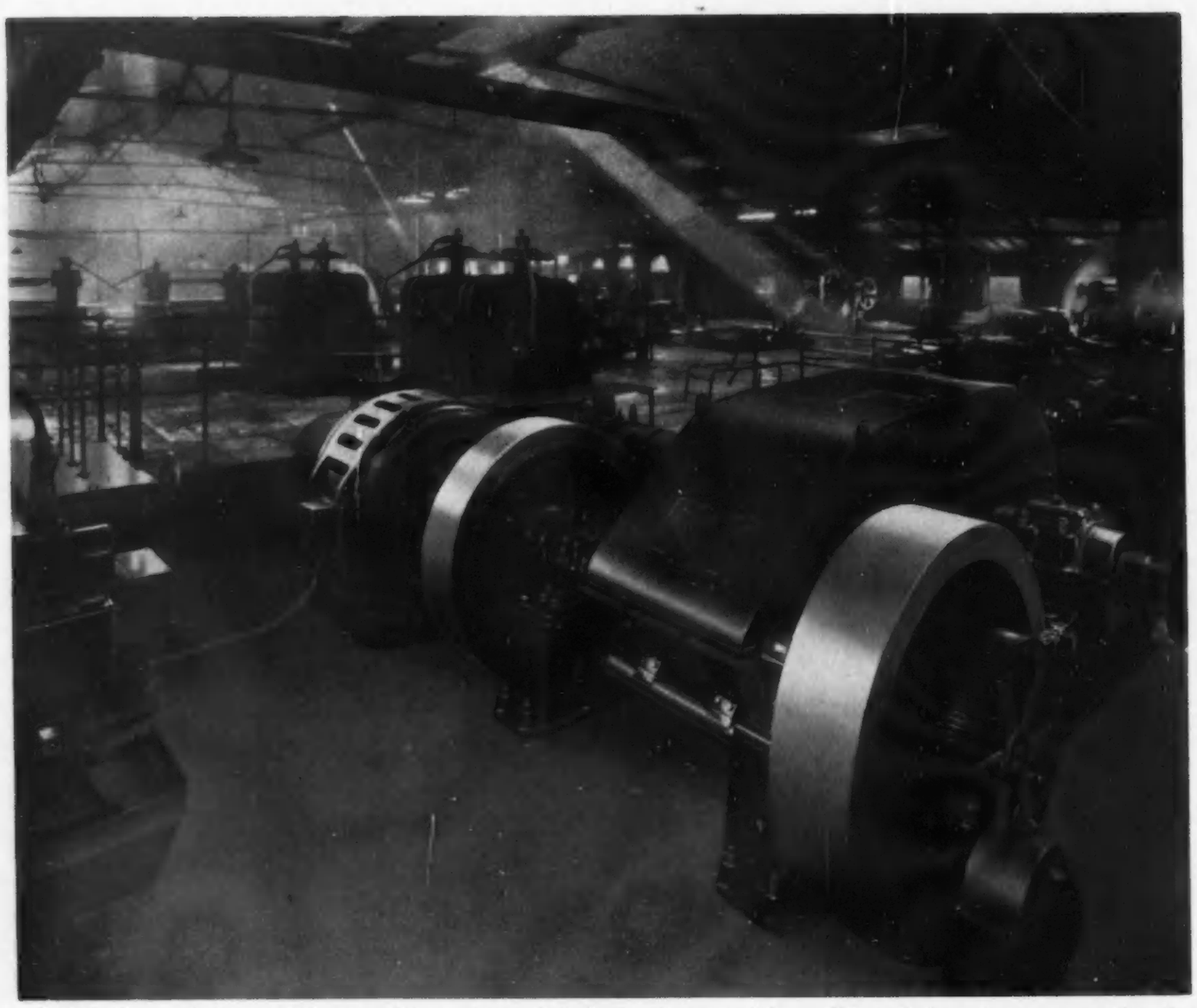

**Fig. 7.—1,000 h.p. A.C. rolling mill motor driving plate mills. The drive is transmitted through gearing, two balancing flywheels being coupled to the motor shaft.**

(*a*) *Slipring Motors.*

The total power lost in the rotor circuit of an induction motor when accelerating is equal to the kinetic energy of the plant driven at full speed.* This holds under all conditions of the rotor circuit. This rotor loss appears in the form of heat, which has to be dissipated if overheating is to be avoided. Further, the rotor current is always balanced by an equivalent current in the stator; if, therefore, the rotor current is high, the loss in the stator will be high, and if the starting period is long an inconvenient amount of heat will be generated in the stator.

It follows, therefore, that plant having appreciable flywheel effect should be driven by a slipring motor. The rotor circuit loss, equal to the kinetic energy, will then be divided between the rotor itself and the starting resistance, the latter taking the major part. In addition, the rotor current can be kept to the minimum consistent with the acceleration required, thus keeping the loss in the stator at a minimum. A few common examples of drives requiring a slipring motor because of the flywheel effect of the plant are given.

1. Rolling mills are usually fitted with flywheels (fig. 7) to equalise the widely fluctuating load caused by the passage of the billet through the rolls, the power taken from the mains consequently being comparatively constant. It will thus be realised that the complete set has appreciable flywheel effect, and comes in the category mentioned above. A further reason for employing a slipring motor is that a falling speed torque characteristic is necessary so that the motor tends to slow down on heavy loads, allowing the flywheel to deliver its energy to the load; this can be effected by the insertion of a permanent, or slip resistance, in the rotor circuit.

2. Fans for running at a slow-speed have runners of a large diameter introducing an appreciable flywheel effect.

3. For mine ventilation purposes a fan often has to accelerate a long column of air which is equivalent to accelerating a flywheel. This can be avoided by fitting a damper in the air circuit so that the fan will start up under reduced load, the damper being gradually opened as soon as the fan had gained full speed.

Apart from the question of flywheel effect, many drives require slipring motors in order to obtain

* Dreese, Proc. A.I.E.E., June 1928.

a heavy torque during the starting up period, and to illustrate these the following typical examples are given.

4. Tube and ball mills are used in the cement and ore crushing industries and consist fundamentally of a steel cylinder containing a number of steel balls. The cylinder is driven through gearing at a comparatively slow speed and projections from the inside move the balls from the bottom of the cylinder to the top whence they fall by gravity and crush the limestone or ore, which is fed into the cylinder. When the cylinder is at rest, the balls and raw material collect at the bottom, their weight constituting a heavy unbalanced force which has to be overcome at the moment of starting by a torque considerably in excess of that at full load. In practice the starting torque usually specified for mills of this type varies from 1.75 to 2.5 times full load torque.

5. Reciprocating pumps and large compressors offer a high and irregular opposing torque at starting, the period of maximum torque occurring on the compression stroke.

6. Where frequent starting and stopping with the need of accurate control are necessary features, such as in electric coal winders, the motor is usually of large or fairly large size, and the whole equipment, including an appreciable length of steel wire rope, expensive. Mechanical shocks to the system must therefore be avoided. Moreover, the winder has to raise a certain number of tons of coal per hour, necessitating a certain number of trips which must be accomplished with a minimum consumption of energy. All this involves working to a fairly definite time schedule, and thus full control, such as is given only by a slipring motor, is necessary.

7. Haulage motors are used extensively in the mining and quarrying industries. The particular duty varies appreciably in different cases according to the weight to be hauled, the slope of the workings, and the number of trips per hour. Generally it consists in accelerating and hauling loaded tubs up an incline by means of a rope wound on a drum driven through gearing. The normal torque required for acceleration may vary between one and a quarter and twice full load torque and may be even higher in the event of any obstruction on the rails.

8. Where accurate control is required for inching, as in the case of hoisting motors for cranes, this can be effected to some extent on small sizes with two-speed squirrel cage motors giving a full speed and, say, a one-third speed by means of a separate stator winding, the deciding factor between the two types depending on the accuracy of control required. If, for example, a crane is handling coal, less accuracy would be required than for handling fragile goods such as cases of eggs or glassware, or for use in the erection shop of an engineering works. In practice squirrel cage motors are only specified for this drive in a very small proportion of cases.

9. Motors of any appreciable size engaged in a duty involving frequent reversals must be of the slipring type. A typical example is the live-roll motor used in the steel industry for handling hot ingots between the passes through the rolling mill.

(*b*) *Squirrel Cage Motors.*

Most of the A.C. motors being installed at the present time are of the squirrel cage type, the use

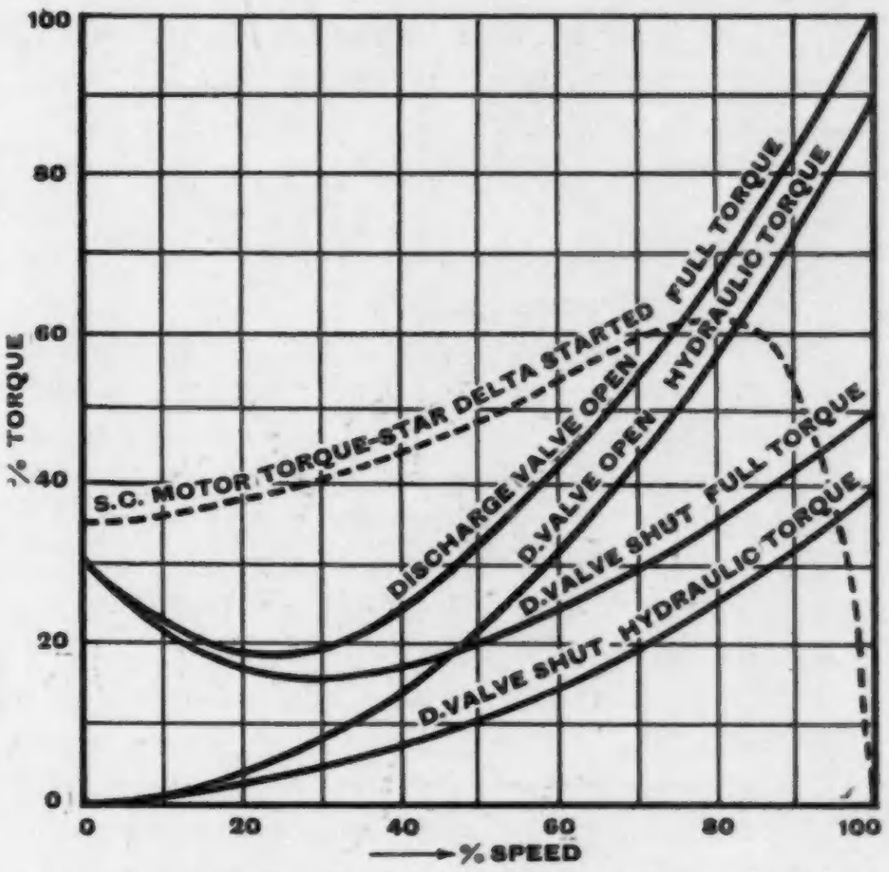


**Fig. 8.—Speed-torque characteristics of a centrifugal pump drive.**

of which is extending both as the result of experience, and the relaxation of supply restrictions, particularly where a bulk supply is taken. Typical examples are given below of drives which can satisfactorily be undertaken by straight squirrel cage motors, providing the supply regulations do not prohibit their use.

1. Line Shafting.

2. Centrifugal pumps. The torque required in starting up a centrifugal pump is shown in fig. 8 (reproduced by the courtesy of The Rees-Roturbo Co.) which is representative of high efficiency pumps taking 100 to 150 h.p. The torque may be regarded as consisting of two components, (*a*) the frictional torque, principally due to the glands and bearings, having a value at starting of about 30 per cent. of F.L.T. and falling away as the pumps speed up; (*b*) the hydraulic torque, which is zero at starting and increases in an approximately square-law as the speed of the pump rises, reaching full load torque at full speed with the delivery valve open, and about 50 per cent. full load torque with the valve shut.

Superimposed on these curves is the speed-torque curve for a star-delta started motor, which also represents one started by auto-transformer on 60 per cent. tapping. These curves show that a pump with these characteristics can be driven by a squirrel cage motor provided the discharge valve is shut during starting.

3. High speed fans. Fan drives should always be given careful attention, as the conditions may be similar to those outlined in connection with mine ventilation.

4. Small compressors fitted with unloading device.

5. A large number of machine tools used in engineering, and many automatic machines used in other industries.

6. Endless rope haulages with friction clutches.

7. Small conveyors.

8. Motor generator sets.

9. The use of squirrel cage motors may also be extended by the fitting of centrifugal clutch pulleys, couplings, etc. In their best form these have springs controlling the clutch weights; the action of the spring allows the motor to attain a high speed before load is applied. This type is preferable to the non-spring controlled type, though slightly more expensive.

10. It has been stated above that drives involving frequent reversal require slipring motors; if, however, the losses over the whole duty cycle can be dissipated by a squirrel cage motor, then it is obviously possible to use this type.

An examination of individual cases, however, will show that this possibility is limited to motors having relatively light duties or small outputs. A motor having a rotor with low kinetic energy has an advantage in such cases, and, if the demand for one particular output were sufficient, it would be worth while making it with a smaller diameter than usual to attain this end.

### HIGH TORQUE MOTORS.

High torque motors occupy a place between the straight squirrel cage and the slipring types, their chief advantage being the ability to give 60 to 70 per cent. of full load torque with a star-delta starter, taking 1.5 to 1.7 times full load current. They have a very wide application since they may be used not only for all the drives mentioned above for squirrel cage motors, in installations where it is desired to reduce the starting current, but also in cases where the starting torque required is too high for a straight squirrel cage motor. For example, the starting torque required for line shafting, fans, machine tools and conveyors, may in individual cases, require a starting torque which, although not sufficiently high to justify the use of a slipring motor, would be too high for a squirrel cage motor. In such a case a high torque motor and star-delta starter offer a satisfactory but appreciably cheaper alternative. Since the advantages of the high torque motor disappear after it has attained 60 per cent. at full speed, the point should not be overlooked that unless a high torque motor is required either on account of starting torque or starting current, a straight squirrel cage motor is preferable both by reason of lower first cost and better running performance.

### CHANGING OVER FROM D.C. TO A.C.

At the present time many industries are changing over from D.C. to A.C. and the problem facing the engineer responsible is to choose a suitable type of 3-phase, 50-cycle A.C. motor to replace an existing D.C. motor. Where series motors have been installed for drives requiring heavy starting torque it is almost certain that the new motor should be of the slipring type; this will also usually apply to compound wound motors. In the case of shunt motors however, the requirements of the drive should be studied and data obtained by including in the survey of the existing D.C. motors a measurement of the starting currents. While this may be accomplished by using stepped resistance starters, more accurate measurements could be made by temporarily connecting liquid starters in circuit. If, then, a certain shunt motor which, when running on full load, takes a full load current of 20 amps., requires a minimum of 30 amps. to start up, representing 150 per cent. of F.L.T., the replacing A.C. motor should be of the slipring type. Or again, it might be found that 10 amps. would bring the plant up to speed quickly, whereas with 8 amps., the starting would be perfectly satisfactory but slower. In this case it is known that 40 per cent. of F.L.T. is required to give the slower starting and that the existing D.C. motor may be replaced by a suitable squirrel cage motor with star-delta starter. In a case where plant driven by a slipring motor is being duplicated, a similar survey would determine whether the motor should be duplicated or whether a squirrel cage motor would prove satisfactory and effect a saving.

### CHANGE-SPEED MOTORS.

Where an induction motor is required to give speed variation over a wide range, this is accomplished by a slipring machine with a rotor control. If most of its work is effected at full speed it will be satisfactory from an economic point of view, but if at a lower speed, the power lost in the regulator resistance may render it uneconomical. Speed variation may also be obtained by the use of a two-speed slipring motor, a commutator motor, or, in extreme cases, a Ward-Leonard set and a D.C. motor.

Where starting conditions are suitable and where two definite speeds are required, change-speed squirrel cage motors will be found perfectly satisfactory. The motor may be of two types :—

(*a*) *Change Pole Motors.* For speed ratios of 2/1, a suitable machine may be made with a single-stator winding, so arranged that the number of poles produced by the stator winding can be altered in this ratio by changing the connections. The principle of the change in pole numbers and one possible arrangement of the windings is illustrated in fig. 9.* It should be noted that, except by the use of quite special switchgear, change-pole motors cannot be made suitable for star-delta starting and must either be switched direct, or started by an auto-transformer. This is a point not always appreciated.

(*b*) *Double-wound Stator Motors.* These can be made suitable for any two speeds consistent with the supply frequency and a whole number of pole pairs. As the name suggests, they have two distinct windings on the stator, each of which is responsible for one speed only. Such motors can be made for any method of starting, a change-over switch being necessary to switch from one speed to the other. Where star-delta starting is required, a six-pole change-over switch is necessary, but even so, the complete equipment is cheaper for small sizes than a change-pole motor with auto-transformer starter, and for this reason is sometimes preferred for ratios of 2/1.

Two-speed squirrel cage motors are frequently used in the following instances :—

1. Machine tools, where two operations are done at differing speeds, *e.g.*, a lathe may be arranged to take a rough cut at slow speed and a finishing cut at high speed ; tapping machines may be arranged to tap at low speed and withdraw at high speed ; a draw bench may be used at different speeds for different gauges.

2. Boiler house fans where different draughts may be required under different loadings.

3. Centrifugal pumps, where smaller quantities of fluid may be dealt with at various times.

4. For technical processes in various industries, such as art-silk, printing, etc.

5. High-speed lifts, involving a special application of two-speed squirrel cage motors. Formerly, A.C. lift motors were almost invariably of the slipring type, but in recent years it has been the practice, both here and in America, to use squirrel cage motors of the two-speed, high torque, high resistance rotor type, started by switching direct on the line. The power required by a lift does not often exceed 20/25 h.p., the majority being of the order of 10/12, or less. Thus, small outputs only are involved.

* "The Control of the Speed and Power Factor of Induction Motors" by Miles Walker, M.A., D.Sc.

The usual method of working is to start by switching the high-speed winding direct on the line, when the motor develops 2 to 2¼ times full-load torque with about 3 to 3½ times full-load current ; the lift is accelerated and continues to travel on this winding. When approaching the required floor the slow-speed winding is switched in and the lift is decelerated down to the slow speed, the motor acting as a brake

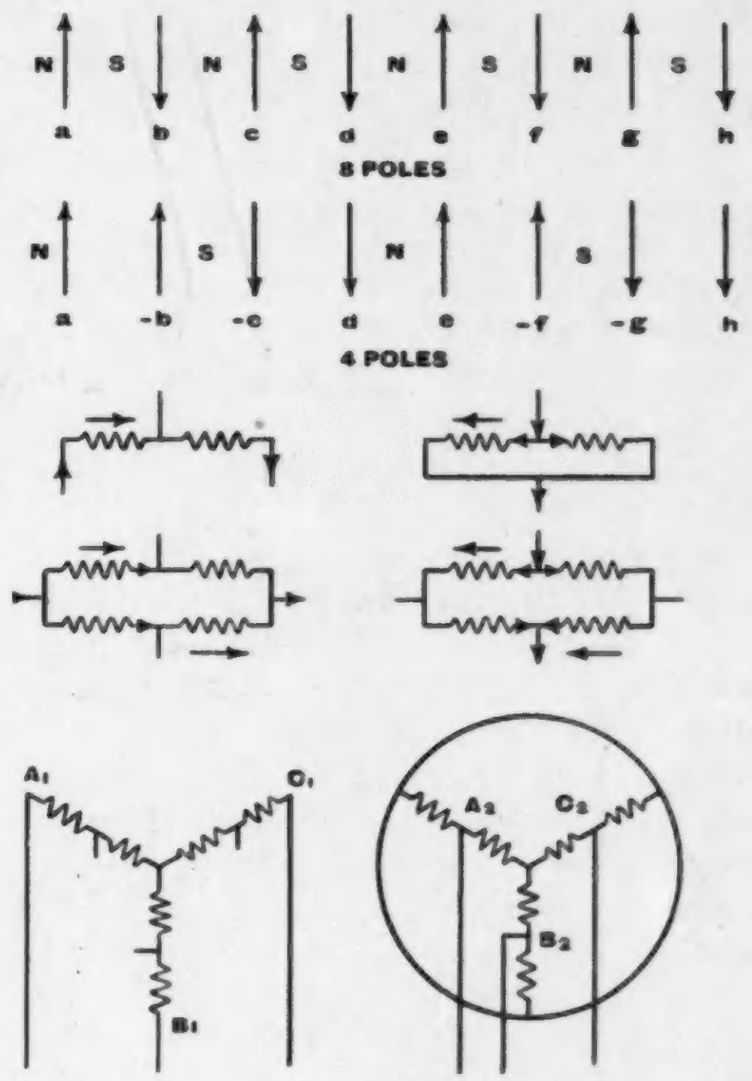


Fig. 9.—Arrangement of pole changing windings.

and the lift being finally brought to rest by a solenoid brake. The advantages of two-speed squirrel cage motors are simplicity of control and the even braking afforded by the slow-speed winding.

### MOTORS SUITABLE FOR TWO FREQUENCIES.

The decision to standardize frequency in this country has brought with it the demand for motors suitable for use on either of two frequencies, *i.e.*, the existing frequency of 25 or 40 and the standard frequency of 50 cycles per second. The first requirement of such a motor is that its output and speed shall not differ by an amount likely to inconvenience the user and, secondly, that its performance as regards efficiency, power factor, or torque, shall not be unduly impaired. Since the motor speed, with a given number of poles, varies directly as the frequency of supply, it follows that for constant speed on different frequencies, the number of poles must be changed. In the case of 25/50 cycles, the number of poles must be doubled, and this is readily effected by means of a pole-

changing arrangement similar to that already mentioned in connection with two-speed motors for 2/1 speed ratio.

A dual-frequency 25/50 cycle motor, therefore, fundamentally consists of a motor in which the stator winding in the case of a squirrel cage motor, and both stator and rotor winding, in the case of a slip-ring motor, are arranged so that the number of poles can be doubled by alteration of the connections at the terminals.

The case of 40/50 cycles is more difficult, since in this instance the number of poles must be increased by 25 per cent. Two facts are clear, firstly, that no simple method of pole changing can be used and, secondly, that only two synchronous speeds of those found in usual practice are common to both frequencies, namely, 600 and 300 r.p.m., although several others between these two are near enough for practical purposes. Above 800 r.p.m., the differences are comparatively wide, as is shown in the accompanying table.

There are two approved methods of approaching this problem. Firstly, by making a motor which will run on both frequencies with a 25 per cent. increase in speed on 50 cycles, and arranging for the drive to be altered by fitting a smaller pulley, chain sprocket or gear, as the case may be, so as to keep the driven speed constant when the change over occurs. In some cases where the higher speed is not objectionable, this would be unnecessary. Such a motor is known as a 40/50 cycle interfrequency motor.

Secondly, by designing the motor in the first instance so that when the change over is due it can be dismantled and the coils forming the windings re-grouped, to give as nearly as possible 25 per cent. more poles, *i.e.*, nearly constant speed. Such a motor is known as a 40/50 cycle dual-frequency (re-connect) motor.

| POLE PAIRS | FREQUENCY | | |
|---|---|---|---|
| | 25 ~ | 40 ~ | 50 ~ |
| 2 | 1500 | 2400 | 3000 |
| 4 | 750 | 1200 | 1500 |
| 6 | 500 | 800 | 1000 |
| 8 | 375 | 600 | 750 |
| 10 | 300 | 480 | 600 |
| 12 | 250 | 400 | 500 |
| 14 | 214 | 343 | 428 |
| 16 | 187 | 300 | 375 |
| 18 | 166 | 266 | 333 |
| 20 | 150 | 240 | 300 |

In conclusion, it may be said that the whole subject of the design and application of these motors to meet the change-over conditions is one of great interest. In the case of 25/50 cycles it is largely a question of motor design, while for 40/50 cycles it is more a question of application, and one in which the contractors and plant manufacturers play a most important part.


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